POTATO CULTIVATION

Department of Agriculture, Bombay

BULLETIN No. 102 OF 1920

INVESTIGATIONS ON POTATO CULTIVATION IN WESTERN INDIA

BY

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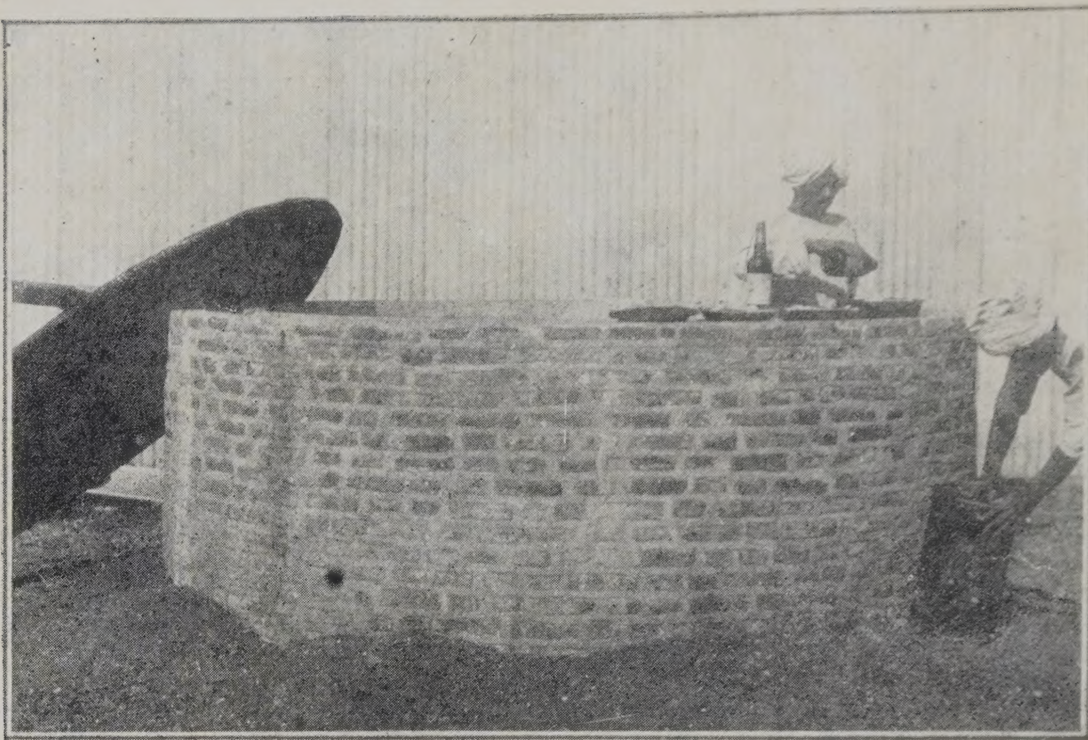
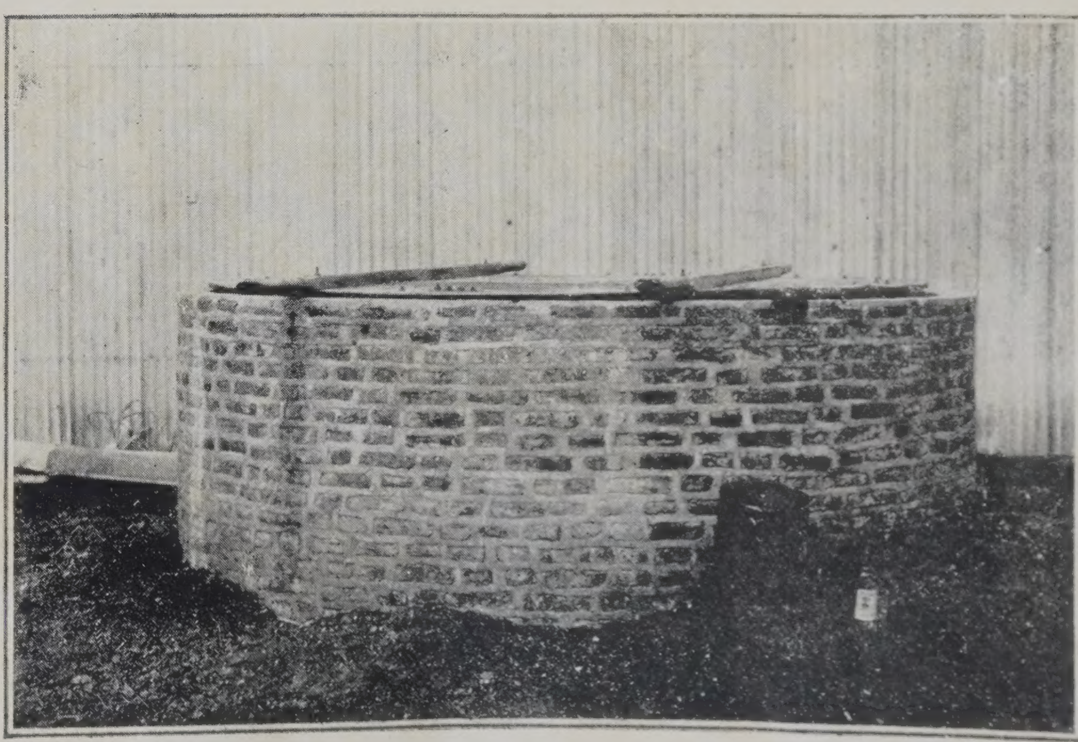
PLATE I.

(*Frontispiece.*)



Fumigation Chamber as used in the Khed Potato Tract. (1) Open.

PLATE I.



Fumigation Chamber as used in the Khed Potato Tract. (2) Closed.

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INVESTIGATIONS ON POTATO CULTIVATION IN WESTERN INDIA.

The cultivation of potatoes in Western India does not occupy altogether a very large area, but its possibilities are enormous, and, this being the case we have undertaken the ' · of this crop, with a view to its improvement and ex- ension. The present bulletin consists, in fact, of a description, by personal survey, of the conditions in several of the areas as they are at present, and of the difficulties and deficiencies revealed. Beyond this we have described what has been done in time past in the way of experiment to remove those deficiencies and also our own experiments since 1916 in studying these difficulties and in devising and ·ilarising methods for meeting them.

have actually studied the potato and its cultivation ·e or four centres in the Deccan and Karnatak must first indicate the conditions in each of these

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·ATOES IN THE KHED TALUKA OF THE POONA DISTRICT.

By S. D. Nagpurkar, B.Ag.

Of all the areas of potato cultivation in the Bombay Presidency that which occurs in the Khed taluka of the Poona district is considerably the most important. The area under the crop has in the past twenty-five years varied from little more than 3,000 acres (3,346) to a maximum over 8,000 acres (8,·69) in any one year. The variation in acreage is shown following table, which also indicates the proportion ·tatoes cultivated in this taluka to the whole culti- this crop in the Poona district. The famine of ·which was especially severe in the potato tracts where ·itation had previously been almost unknown, com- · the impossibility of importing fresh seed suitable ·ct from Italy owing to war conditions, has almost ·collapse of the industry in 1919-20. The area

has, in fact, nearly sunk to nothing. This collapse is, however, temporary, and there is no doubt that the industry will recover rapidly if seed is available :—

Year.	Area under Potatoes.		Proportion in the Khed Taluka.
	Khed Taluka.	Poona District.	Per cent.
1890-91 ..	4,429	6,463	68·3
1891-92 ..	5,480	7,771	70·5
1892-93 ..	5,263	6,781	77·6
1893-94 ..	4,993	7,563	66·0
1894-95 ..	5,273	7,173	73·5
1895-96 ..	7,160	9,245	77·4
1896-97 ..	4,906	5,557	88·3
1897-98 ..	5,349	6,313	84·7
1898-99 ..	6,159	7,141	86·2
1899-1900 ..	4,094	4,445	92·1
1900-01 ..	4,133	4,851	85·2
1901-02 ..	6,591	7,594	86·8
1902-03 ..	7,646	8,724	87·6
1903-04 ..	8,369	9,698	86·3
1904-05 ..	3,424	3,789	90·4
1905-06 ..	3,346	3,543	94·4
1906-07 ..	3,495	4,032	86·7
1907-08 ..	5,535	6,385	86·7
1908-09 ..	4,980	5,626	90·6
1909-10 ..	5,936	6,905	86.0
1910-11 ..	5,654	7,389	76·5
1911-12 ..	5,504	6,238	88·2
1912-13 ..	4,967	5,442	91·3
1913-14 ..	5,153	6,026	85·5
1914-15 ..	5,133	6,345	80·9
1915-16 ..	6,909	5,889	85·2
1916-17 ..	7,745	5,917	76·4
1917-18 ..	4,916	4,586	93·3
1918-19 ..	2,614	2,344	90·0

These figures show that, if we exclude 1918-19 and 1919-20, while there have been considerable variations in the annual area, yet there has been little permanent alteration in the extent of the potato cultivation. This is better shown by the following figures giving the average area in the Khed taluka for each five years since 1890 :—

		Acres.
1890-1894	..	5,087
1891-1895	..	5,633
1892-1896	..	5,519
1893-1897	..	5,536
1894-1898	..	5,769
1895-1899	..	5,533
1896-1900	..	4,908
1897-1901	..	5,265
1898-1902	..	5,724
1899-1903	..	6,166
1900-1904	..	6,032
1901-1905	..	5,875
1902-1906	..	5,256
1903-1907	..	4,833
1904-1908	..	4,156
1905-1909	..	4,658
1906-1910	..	5,120
1907-1911	..	5,521
1908-1912	..	5,408
1909-1913	..	5,442
1910-1914	..	5,280
1911	..	5,504
1912	..	4,967
1913	..	5,753
1914	..	5,133

There was a fall in area in the famine period from 1896 to 1900, and again a larger fall in the years following 1903, which seems probably due to a series of years of small

rainfall,—but otherwise, the normal area in the taluka seems to be between five and six thousand acres rising a little higher when conditions are favourable and falling a little when rain is short, good seed is difficult to get, or when there is some other special temporary factor influencing the cultivation.

The area too forms a fairly constant proportion of that in the Poona district, at any rate since 1895,—as the following average figures show :—

Years.		Proportion of the total area in the Poona District.
		Per cent.
1890-1894	..	71·2
1895-1899	..	85·7
1900-1904	..	87·2
1905-1909	..	88·8
1910-1914	..	84·4

How long the growth of the potato has existed as an intensive culture in the Khed taluka, we cannot tell. Inquiries of the oldest people in the villages led to no information,—but potatoes were grown near Junnar as far back as 1841.

Soon after the Agricultural Department was established, one of the matters which came to its notice was the existence of a serious potato disease which was doing great harm in the Khed taluka, and for several years the annual reports of the Agricultural Department * contained a good deal of reference to this disease, and two bulletins † were also issued on the subject, the second one (in 1893) describing the conclusions which were reached. This disease, termed '*bangdi*,' is still common, and does, still, a very great deal of damage to the potato crop of the taluka. It was dealt with by using Italian seed, which was found to be almost if not quite free from the disease, and *perhaps* to be resistant to it.

* Annual Reports of the Director of Agriculture, 1890-91, 1891-92, 1892-93, 1893-94, 1894-95, 1895-96.

† Agricultural Department, Bombay, Bulletins 13 (1892), 16 (1893), Agricultural Ledger No. 4 of 1905.

Since the time when this disease was so much discussed little reference to this important agricultural industry in Khed exists in the reports, papers, or bulletins issued by the Agricultural Department.

The cultivation of potatoes as carried out in the Khed taluka varies in method to a considerable extent. There are two crops in the year. In the older bulletins it is stated that the *kharif* crop is only taken in order to provide seed for the larger *rabi* crop. This is the case in some villages, but not by any means in all, and in a number of villages the *kharif* crop is more extensive. In Chakan, for example, the *kharif* crop is very small, almost entirely for seed purposes ; in Peth and the surrounding villages, on the other hand, the *kharif* crop is much larger in proportion. The relative acreage of the two crops in five recent years in the taluka is shown in the following figures which give the area in villages only which have grown more than one hundred acres in any year :—

		Kharif.	*Rabi.*	*Rabi.*
		Acres.	Acres.	Percentage of Total.
1910-1911	..	1,209	2,441	67
1911-1912	..	1,215	2,439	67
1912-1913	..	1,020	2,042	67
1913-1914	..	1,412	2,304	62
1914-1915	..	1,453	2,914	67

We shall first describe the method of cultivation in vogue for the *rabi* or cold weather crop in several typical centres, and then indicate the difference in the practice with the *kharif* or rains crop. At Chakan, where perhaps the greatest care is taken, the land on which it is intended to plant potatoes is shown with *bajri* which is harvested in September. Immediately after this, as soon as the condition of the soil allows it, the land is ploughed with the usual wooden plough of the Poona type, with three to four pairs of bullocks. After a week a second cross ploughing is carried out, the

clods are then broken with a harrow, and the field made level. After this twelve to twenty cartloads, or say 10,000 to 16,000 lbs. per acre of usual village manure are carted to the field, and made into small heaps at regular intervals. Then follows the making of furrows with a small plough (*nangari*), this being generally done in the beginning of November, but the exact time depends on the condition of the land. The furrows are six inches apart.

The seed is now immediately sown. This is generally of a round white Italian variety which has proved itself an excellent yielder and fairly resistant to the *bangdi* disease. It has been in the past especially imported from Italy, and most cultivators have tried to obtain new seed say at least once in four years. If not obtained it seems to be the usual custom to try and get seed from another village, especially a village to the west, in the *Mawal* tract, if the seed is needed for the *rabi* crop. A good deal of land is, however, planted with seed bought simply for the purpose from the local or the Poona bazar. In Chakan the seed employed by the ordinary cultivators is mixed to the extent of about two per cent. with a long red variety stated to be from Mahableshwar, but which we now know occurs in the Italian seed as imported.

The universal seed rate given seems to be four pallas of 280 pounds, or 1,120 pounds per acre. The seed is always cut into pieces according to the size of the potato. The cut sets are examined for ring disease (*bangdi*) and if it is seen to any considerable extent in the sets, the whole is rejected. Little notice is, as usual, taken of a small amount of ring disease in the seed. The seed is sown by hand, the bottom of the furrow being covered with manure before the sets are put in or else the manure is scattered over the planted sets. The sets are placed nine inches apart and thus the maximum number per acre is 80,000. After sowing, *wafas* (beds) are made, each including five *saries* (rows). Then the sets are watered with irrigation water. The sowing,

wafa making and watering are done on the same day, and watering is repeated after fifteen days. This watering is termed *ambawani*. Another watering after a further twelve days is termed *chimbawani*. If the seed has been good by this time germination will have taken place and the shoots are visible on the surface, and weeding is therefore possible and is done.

Following this the crop is earthed up,—an operation carried out in Chakan but not in most of the other villages of the tract. This operation is termed *khandani* or *bharani*. It is done by hand labour, the ordinary *kudal* or *hoe* being used for the purpose. Thereafter regular watering only is needed every tenth or twelfth day and occasional weeding.

Harvesting is usually carried on when the plants are yellow and show signs of drying. The best cultivators, however, prefer to harvest at rather earlier than this stage. Little difference is made here as to the time of harvesting for seed and for market, except that the first harvested are generally kept for seed. The digging up of the tubers is done by the small *nangari* plough previously referred to.

Harvesting usually occurs 3½ months after sowing. After the potatoes turned up by the first operation with the *nangari* have been collected, the land is worked again with the same implement, and another lot is turned up and collected. The operation is repeated several times until no more tubers are obtained. Only those turned up in the first ploughing are taken away and stored for seed : the remainder are at once sent away to market for sale. We will deal separately with the methods of storage used by the people.

The actual outturn which the cultivators expect to get is from eight to twelve times the amount of seed potatoes employed. This is, therefore, from 8,960 pounds to 13,440 pounds per acre or say 4 tons to 6 tons per acre. Occasional records there are of crops having gone up to fourteen to sixteen times the seed used or 8 to 10 tons per acre, but

these are rare and until recently were hardly believed among the people themselves.

Apart from the difficulties of seed and disease, with which we will deal separately, the gradual reduction in the quantity of manure available is one of the serious matters on which stress is laid by the people. The reduction in the available fodder by the absorption of all surrounding grass areas for the commissariat department has caused a reduction in the number of cattle and hence in manure. So far artificial manures have not been used in Chakan, but there is little doubt that if introduced after due trial the potato cultivators would be prepared to use them, and would purchase them in large quantities.

Such are the methods and difficulties which prevail at Chakan. The methods in vogue at other centres are on the whole similar, but there are differences which are worthy of record.

At Khed the cultivation is almost entirely carried out in beds and not on ridges as at Chakan. The crop is never earthed up. This was obviously a disadvantage, and seemed to result in the prevalence of the disease termed *ubla* or *buri* (*Rhizoctonia*) which was hardly noticed at Chakan at all in the *rabi* crop. Of this, however, more later. The seed rate was similar to that at Chakan or four *pallas* (1,120 lbs.) per acre. The amount of manure was less (from ten to sixteen cartloads, or 8,000 to 13,000 pounds) though as much was put on the field as was available. The same complaint of the reducing quantities of available manure was made here as at Chakan,—but here, at any rate repeated experiments with artificial manure have been made, and made with success. They have been so successful that a market for artificial manure, when the price falls, is assured.

The average yield of potatoes at Khed is less than at Chakan as would be recognised as likely on account of the bed system of growing and the smaller quantity of manure.

The yield was in fact estimated by the people at six to eight times the amount of seed or three to four tons per acre. Ten to twelve times the amount of seed was considered very high though it was recognised that in the experiments with artificial manures even bigger yields than this (up to fifteen or sixteen times the seed) have been obtained.

The land rises to a higher plateau north of Khed, with higher but good soil, and on this plateau potato cultivation has developed extensively in a series of villages in which the cultivation is very similar. It is interesting to note that in several of these villages (including Peth) the *kharif* is proportionately a bigger crop than in the villages to the south.

In this upper plateau the soil used for potatoes is lighter than at Khed and Chakan, as has already been stated. It consists of a reddish, somewhat *murmad*-like soil, not very retentive. The best of all, as in some plots at Awasari (on lower land again to the north), is where this material has been washed down into hollows near the banks of rivers and streams. It is usually ploughed twice, then the clods are broken and pulverised, and afterwards twelve to sixteen cart-loads (10,000 to 13,000 lbs.) of farmyard manure per acre is given and mixed with the soil of the whole field by ploughing, By means of the *nangari* (working with two bullocks). furrows are made, and the cut sets planted in them nine inches apart. The sets in one furrow are covered by the operation of opening the next furrow. Then *wafas* (beds) are made, each bed being ten feet long by five feet broad, and the whole field is irrigated in the same way. The further treatment is that usual elsewhere. Earthing up is not practised.

The crop obtained from the usual sowing of 1,120 pounds per acre is on an average from six to eight times the seed used. In one very exceptional case, in beautiful soil near the banks of a stream, a cultivator claimed that he would obtain twenty times the seed or ten tons per acre. The crop

was an exceedingly good one without manure, but the yield suggested is very high for this area.

Thus taking the district as a whole, the *rabi* crop of potatoes grown by the methods described, yields about six to twelve times the amount of seed used, and in exceptional cases higher than this. From the accounts of the cultivators, it would appear that the average cannot be more than four tons per acre. Farmyard manure only is now used in growing this crop, and the amount of this available tends to decrease. The potato used was invariably the Italian white round, though a small admixture with a long red potato was almost everywhere found,—and this white round potato was stated to have the best market in Poona.

The crop grown in the *kharif* season is smaller in extent, as has already been noted, than that produced in the *rabi*. It is, of course, dependent either solely or almost solely on rainfall, irrigation being either not used or hardly used at all except in case of absolute necessity. So far as actual methods in vogue are concerned, the following differences from those already described are found.

The crop is usually grown after gram or wheat, the land being ploughed at the end of February or the beginning of March, and one or two further cross ploughings being made at intervals of fifteen days. Farmyard manure is put in heaps in the field at the end of April at the rate of twelve cartloads (10,000 lbs.) per acre. This is mixed with the soil by means of the *nangari* or small plough. After the rains commence, the soil is well saturated with water, and after the surface has become dry enough to form a friable tilth, furrows twelve inches apart are made with the small plough and the sets planted in the furrows at a distance of nine inches between them. The seed rate is about 900 pounds per acre in this season. The whole seed is then covered with a harrow and the field thus made level. The first

weeding occurs one month later and a second weeding after a further fifteen days.

Germination generally occurs at least before fifteen days and the potatoes are harvested after three months' growth. The land usually put under potatoes in the *kharif* season is not capable of being irrigated, so that failure of rain generally means failure of crop. The harvesting is done by hand digging and not by the *nangari* as with the *rabi* crop. The yield obtained is from four to six times the seed, or 4,000 to 5,000 pounds per acre, being thus less than in the *rabi* season crop. The great enemies of the crop at this season is the prevalence of rhizoctonia blight, and the attack of the *tambera* disease.

II.—THE MAHABLESHWAR AREA OF THE SATARA DISTRICT.

By S. D. Nagpurkar, B.Ag.

While the elevation of the Khed area above the sea is from 1,800 to 2,000 feet, the Mahableshwar potatoes, grown at a much higher elevation than the greater part of the Deccan (4,000 to 5,000 feet) and near a popular hill station, have received far more attention than is justified by the extent of their cultivation or by their importance. They have been spoken of as a suitable source of potato seed, and as the home of a specially good variety. And yet the total area of potatoes in the Satara district, in which Mahableshwar lies, is only three hundred acres (297 acres in 1914-15), of which less than half lies in the area we are discussing. At the same time it is worth while to describe the conditions prevailing, the methods used, the character of the potatoes planted, and the diseases found,—the last especially, if Mahableshwar is to be considered as a source of seed.

The whole cultivation is simply a series of patches chiefly in the upper part of the Yelwa and other valleys to the east

of Mahableshwar. The cultivation is hence almost entirely by hand, but is carried on by a very industrious lot of cultivators, hard-working and intelligent. The methods used can be illustrated from those in some of the villages visited.

Two crops of potatoes are taken each year, one in the *kharif* and the other in the *rabi* season. These are never taken, however, from the same land. For the cultivation in the rainy season, sets are planted on the sides of hills one foot high. The planting takes place in June. In the *rabi* season the seed is planted in furrows, in two rows with the irrigation water flowing between the rows. In the latter case the crop is earthed up after it is one month old. Watering is given for this crop usually every fourth day, though this varies according to the soil and the special climatic conditions. Water is usually found within a very few feet of the surface and is applied by means of the well-known *pycotta*, an instrument otherwise very rarely seen in the Bombay Presidency except in Kanara.

After planting the sets are covered with farmyard manure, two handfuls per set, and then the whole is covered with soil. The sets are obtained by cutting the potato into three to four pieces according to the position and number of eyes.

After harvesting, the potatoes are sorted carefully and heaped up in a corner of the house, and covered with the leaves and branches of the fern so common in the neighbourhood. They are then separated from the rest of the house by a curtain of the same fern with a small hole for the owner to enter. No one else is usually allowed to approach the store.

Several varieties of potato are grown known by the following names:—(1) Kidney—*Khirani*—*Mumbasa*, (2) Bengal kidney, (3) *Malti*, (4) *Gulabi*, (5) *Tambada*, (6) American. The characteristics of each of these varieties will be described later. It was reported to us by old people that the original Mahableshwar potato was the *Tambada*, a red variety

which was introduced by the Chinese who were prisoners there forty years ago. It was very productive, and also kept well, but the people became careless about seed preservation, and ultimately had to buy seed from Bombay (Italian) locally called *Gulabi*. This was stated to deteriorate rapidly unless new seed was frequently obtained. The actual crop is very mixed indeed and tubers of *Gulabi*, *Tambada* and *Khirani* were picked from one heap.

The yield expected by the people, if good seed is used, is eight times the seed employed. But recently, good Bombay seed has not been obtained, and the result is that large numbers of plants die in the field before maturing and the outturn is decreasing. It is the same complaint as is found in other centres and the demand for good reliable seed is insistent.

In inspecting the crop in the field and the potato in the stores* we found that almost all the diseases which we have noticed in the Deccan were rife in this area. Among insects the potato moth was very common and did much damage, and in addition very large damage was done by the larvae of another moth (*Leucinodes orbonalis*). These cut through the stem and destroy many plants in some villages. Cutworms also do damage. The fungus and bacterial diseases were still more injurious and we found the crop in every variety riddled with (1) Ring or *bangdi* disease, (2) *Rhizoctonia*, (3) a disease termed *khuzali* by the people, shown to be powdery potato scab (*spongospora*) and (4) a disease in which the top of the plant looks as if burnt up, and now found to be caused by a mite (*Tambera*). We will deal with each of these diseases in a later chapter. We may emphasise, however, that the crop near Mahableshwar is now as much riddled with disease as anywhere else in the Deccan. The idea which has been put forward that we may look to Mahableshwar for fairly disease-free seed is quite wrong. If used, as many precautions will have to be taken here as elsewhere.

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* We had the invaluable help of Professors Ajrekar and Kasargode of the Poona Agricultural College in examining these crops.

The potato crop is also grown in other parts of the Satara district to a small extent. These areas lie at about the general level of the Bombay Deccan (2,000 feet) and the methods do not differ widely from those used in the Poona district. The principal areas are round Koregaon and Wathar, whence the produce can be easily booked to Poona or Bombay. The *kharif* crop is by far the most important and the dominant variety is the same as that found in the Khed tract.

The potatoes of the district are riddled with the diseases found elsewhere. In addition a scale insect on the underground stems, roots, and young tubers was noticed in the village of Pimpli near Wathar. This has apparently not spread at all, and is at present very rare.

III.—POTATO-CULTIVATION NEAR BELGAUM AND DHARWAR.

By S. D. Nagpurkar, B.Ag.

In the south of the Bombay Presidency, in Belgaum and Dharwar there lie other islands of potato cultivation, and the methods adopted command some interest.

In Belgaum the area has been very concentrated in the neighbourhood of the town, and has been of a very intensive character, yielding very high returns. The area has never been more than a few hundred acres, and the potatoes have been almost exclusively grown in the *rabi* season. The land, having borne a crop of rice or grass in the previous rains, is ploughed up in September or as soon after as the previous cropping allows. Four times the plough is run over the land, the clods being broken up by hand and stubbles collected after each ploughing. After harrowing, ridges are made, at a distance of one foot, with the country plough and beds, eight feet by six feet, are prepared for irrigation, three rows being in each bed.

Potatoes are planted first in the furrows in the first week of October or as soon after as possible, and harvested in the following January or February. The sets are planted very close together in the row, the distance being often not much more than four inches. As the plants begin to grow they are earthed up. The seed rate required is, hence, very high, usually about 1,800 pounds per acre. Watering is given every eighth day in the first month, every fourth day in the second month and again every eighth day in the third month. The land is weeded twice during the growth.

If potatoes are taken after rice, no manure is given ; if after grass twenty-five cartloads (20,000 lbs.) of farmyard manure per acre. The average yield is from 10,000 to 13,000 pounds per acre or six to eight times the seed used. As has already been stated, the cultivation in this area is very intensive, and the edges of the water channels in these potato fields are usually planted with cabbage and knol-kohl, which add to the return given by the potatoes. The cultivation altogether is exceedingly good and the potato fields near Belgaum show one of the most attractive forms of agriculture in the Bombay Presidency.

In Dharwar, sixty miles to the south of Belgaum, a very different type of potato cultivation is in vogue. Here the crop is taken exclusively in the *kharif* season, as there are few wells and hence little irrigation in the tract where potatoes are grown. The Dharwar cultivators usually get their seed from Belgaum, this being reaped in January or February and planted in the following June.

The fields in which it is intended to plant potatoes are first ploughed two or three times at the beginning of June after the first rains have been received. The land mostly used is a reddish, fairly porous but deep soil, though some potatoes are also planted on black soil. After harrowing furrows are opened by means of the plough, five to six

inches deep, and three feet apart. Thus the planting is far wider than anywhere else in Western India, and in recent years an intercrop of cotton or chillies is often taken between the rows. A man follows the plough with a basket of farmyard manure, and two handfuls are given for each potato set planted. The sets are put down at twelve to fifteen inches apart in the rows, and each set is placed on the small heap of manure, and partially covered by the hands, with earth and manure. Then a small harrow is passed over the field and the ridges levelled.

When the sets have germinated,—the shoots usually showing above ground after fifteen days,—the land is hoed, further hoeings following at intervals of a month. The hoe used is so arranged as gradually to earth up the rows of potatoes. The plants grow vigorously, the larger space leading to larger and more vigorous plants than are found elsewhere in the Bombay Presidency. This does not mean a very high yield per acre as the amount of seed used is small. From 300 pounds of seed per acre, a yield of 1,500 to 2,000 pounds of crop is expected with the quantity of manure used.

The diseases found are similar to those noted in the *kharif* crop elsewhere. Ring disease is common, and the potato moth is stated to have almost ruined the cultivation as the produce cannot be stored. Rhizoctonia wilt is most common, and the *tambera* disease is rampant and annually reduces the yield to an enormous extent. Among minor pests, the stem borer (*Leucinodes orbonalis*) is very common.

The area here has been very largely reduced on account of shortness of seed, due to the famine of 1918, and the impossibility of importing Italian seed. The potatoes grown at Dharwar are largely bought by Bangalore merchants for seed and it is stated that they prefer for this purpose the tubers grown in black soil.

IV.—CAUSES OF THE LOW YIELD OF POTATOES GENERALLY.

By H. H. Mann, D.Sc., and S. D. Nagpurkar, B.Ag.

The chief causes of the low yield which prevails over most of the potato areas described seem to be threc. The first is that usually a large proportion of the seed potatoes do not germinate. The second lies in the fact that the seed is generally so infested with disease, chiefly potato moth and the bacterial 'ring' disease that either the vitality of the plants is damaged, or they almost inevitably die before the crop is ripe. And, thirdly, there are several diseases of the crop in the field, most of them different from the great potato scourges of temperate climates but nevertheless equally important here, which either kill the plants or reduce their yield, particularly in the *Kharif* season, to very small dimensions. Beyond these causes, the manuring given is by no means sufficient to secure a full crop, and as we shall show, this can be very largely increased by more adequate fertiliser dressings than the people are at present ready to use.

With regard to the losses of plants commonly found due to lack of germination or to disease attacking the potato plants in the field, the effect can perhaps best be seen by actual counts of the number of missing plants in fair average fields of growing potatoes. We have actually counted the blanks in growing fields on several occasions in the Khed area, and the following figures give the results of some of these :—

(1) At Khed an average field was taken and forty-five per cent. of the plants which should have been there were found to be missing.

(2) At Peth a similar test made in a particularly good field gave twenty per cent. of blanks, and an average field showed forty-one per cent.

How far this excessive loss is due to faulty germination and how far to each of the prevalent diseases is not yet quite clear, though certain indications have been obtained. But it would appear that, from one cause or another, there are, on the average between thirty and forty per cent., less plants in the fields of ripening crops than there ought to be.

As to the failure of germination, the people use the term '*rutu*' to express the condition of the seed tubers when they are ripe for germination. So far as the *rabi* crop is concerned, the people in the Khed taluka said to us that they prefer Italian seed because it arrives in a condition in which it is ready to germinate (*rutu*), whereas, owing to difficulties of storage (on account of high temperature, etc.), the local seed is not usually ready to sprout when planted. This is, in popular opinion, one of the chief reasons for the superior yield given by Italian seed.

Potatoes intended for seed are usually reaped slightly before the rest of the crop, when the leaves over most of the plants are yellow but when those at the top remain green. This is, of course, not an infallible guide but gives an idea of the condition which it is generally considered should be reached. When so reaped they may be considered as slightly immature, but their utilisation as seed is in accordance with the latest opinion in Europe, where the use of such slightly immature seed potatoes is considered to promote earliness, vigour, and resistance to the effect of bad seasons.* When reaped, however, they will only germinate to a very small extent, and they have to be stored for several months to become *rutu*. We attempted to germinate sets, very carefully selected from plants in the best condition, immediately after digging up in October. Only about ten per cent. in thirty-three days, and forty-five per cent. more in sixty-three days, germinated. Only when the dug potatoes are green from having been exposed to the air during growth is a higher percentage

* See Hutchinson—Journal of the Board of Agriculture, Vol. 23, page 529 (1916).

of germination obtained. In ordinary cultivation more than twenty-one days to germinate is considered as unlikely to give a decent plant, so that fresh seed, however carefully selected, is quite unsuitable for growing a crop.

But while some eyes do sprout immediately after digging, if the potatoes are kept for a week or more no germination whatever is obtained unless they have been stored for two months at least. This loss of germinating power, after keeping for a few days has been noticed several times, and so storage of seed for a *considerable* time is needed. How long this should be, under Deccan conditions to get the best results has been carefully tested with potatoes reaped in October, and planted from December onward. The following table shows the percentage of germination in two weeks and three weeks respectively with potatoes stored for varying lengths of time :—

Length of storage.		Percentage of germination in 14 days.	Percentage of germination in 21 days.
2 months	..	*Nil.*	*Nil.*
2½ ,,	..	*Nil.*	25
3 ,,	..	15	40
3½ ,,	..	40	70
4 ,,	..	50	80
4½ ,,	..	60	85
5 ,,	..	70	92
6 ,,	..	80	95
7 ,,	..	100	100
8 ,,	..	80	85
9 ,,	..	60	70
13 ,,	..	40	60

These figures show that in the months from October onward in the Deccan storage for two months is not enough, and that the germinating power gradually increases until the potatoes have been kept for seven months. After the hot weather starts the temperature has to be kept down below

90°F. or rotting will commence (see Chapter IX). If this is secured the potatoes keep well, but ultimately shrivel and dry up. This is apparently the cause of the progressive loss of germinating power after seven months.

If the *rutu* condition is to be obtained, as a rule, therefore, in places where both *kharif* and *rabi* potatoes are sown, it will be necessary either (1) to hasten the changes taking place in the stored potatoes so that they may become ready within two months or (2) to store potatoes from the *rabi* crop for the following *rabi* season, and similarly from the *kharif* crop for the following *kharif* season. This alternative means keeping the potatoes for six months.

If the hastening of the *rutu* condition (No. 1) could be produced it would be a great boon in the matter of getting good germination. This can, in our experience, be secured to a small extent by fumigation (as described in the next chapter in connection with the potato moth) followed by storing in bags, as against storing in single layers under sand. This increase in the rapidity of becoming ready for germination, may in the case of storage in bags be due to the somewhat higher condition of temperature which there prevail coupled with a moist atmosphere among the stored potatoes. But the matter is one for which the reason cannot be definitely given.

As regards the other alternative mentioned above (No. 2) it is avoided by the people owing to the difficulty of storage as a result of attack by the potato moth, of the prevalence of dry rot (*fusarium*) and other rots in almost all Indian seed, and (in the hot weather) of the very large loss caused by the heat-rot to be described in a later chapter. To avoid these difficulties means rigid selection and careful fumigation of the potatoes selected for seed, coupled with special storage arrangements whereby the temperature can always be kept below 90°F. at least. We have carried out these methods and have succeeded in obtaining after six months storage

excellent seed potatoes in precisely the same condition as the potatoes imported from Italy at the time they arrive. There now seems no doubt of the feasibility, with due care, of keeping seed potatoes for six months on the Deccan, though it is now never done. We will deal with this matter in the chapter on potato storage (Chapter IX).

The actual amount of failure of plant in average fields has been indicated at the beginning of this chapter, but the figures there quoted were taken when the crop was nearly ripe, and so included all the later losses due to disease attack in the field. A better idea of the amount of failure of plant due to deficiencies of the seed was estimated in the fields not more than two months after the planting of the sets. Good fields only were chosen as it was wished to ascertain the losses in the best practice, and those sets, which had germinated so late that they would never produce good plants, were counted as failures. The estimation was made in the *kharif* season. Thirty such fields were taken, and a row or bed selected at random which should have contained one hundred plants was counted. The actual number of plants, on the average, was twelve per cent. below what it ought to be, but the variation was very large even among good fields. The following statement shows the condition in more detail :—

	Per cent.
Fields with 95 per cent. of the proper number of plants or over	26
Fields with 85 to 95 per cent. of plants ..	40
Fields with 75 to 85 per cent. of plants ..	17
Fields with less than 75 per cent. of plants	17

These figures it must be remembered indicate the state of affairs in fields only which are recognised as good and probably above the average. They also indicate the condition during the early part of growth and before the greater part of the considerable mortality from ring disease and

rhizoctonia occurs. They show that it is possible, with the knowledge possessed by the cultivators, to get good germination with much shorter storage than is indicated in the table given above.

Failure of germination may be due not only to the potatoes not being *rutu* but also to moth attack of the seed during storage, and to the prevalence of the *bangdi* or ring disease, as well as other diseases of the potato tuber. The moth attack and the *bangdi* disease are the most important, by far, however, in the Khed area and they are throughout the district the most dreaded enemies of the potato cultivators.

Careful cultivators in fact take considerable pains to eliminate potatoes seriously affected by moth as well as those attacked by ring disease from the potatoes actually sown. This is done because any eyebud attacked by moth will not germinate,—and a seed potato affected by ring disease will produce a plant which will inevitably die and may infect others. In spite of this a good deal of both useless and diseased seed is sown. We made, in fact, an examination in a large number of cases of the seed ready cut and actually being sown to determine how far the loss of plants was due to seed, with the following results.

We examined the seed being used in thirty-nine fields in the Khed area. Taken altogether, out of 3,856 sets examined :—

(1) 2,669 or 69·2 per cent. was sound and good seed.

(2) 253 or 6·6 per cent. was affected with *bangdi* or ring disease.

(3) 296 or 7·7 per cent. was injured by moth so that some of the eyes would not germinate.

(4) 135 or 3·5 per cent. were so injured by moth that *none* of the eyes would germinate.

(5) 367 or 9·5 per cent. were attacked with dry rot (*fusarium*).

(6) 136 or 3·5 per cent. of the sets had no eyebuds and so *could* not germinate.

Thus we have seven per cent. of the sets which could not possibly germinate at all (Nos. 4 and 6). We have 6·6 per cent. remaining after all elimination has been done, attacked by ring disease (No. 2). These were cut (as they always are) with the same knife (see page 47) as the other sets. The sets partially attacked by the moth would be of variable value, but at least half would produce no plants or at most very feeble ones. The effect of the *fusarium* (dry rot) on the potatoes for seed will be discussed later (Chapter VII). But the fact remains that on the average of thirty-nine separate fields, little more than two-thirds of the seed used was entirely sound in 1917.

Of course the average just given is not quite a fair figure to take. The best cultivators used seed absolutely sound and capable of germination, and the actual character of the seed sown in the different cases is summarised below :—

Proportion of seed sound and capable of germination. Per cent.	Proportion of cultivators using each quality of seed. Per cent.
100	10·3
90-100	7·7
80-90	20·5
70-80	30·8
60-70	5·1
50-60	5·1
40-50	5·1
30-40	5·1
20-30	2·6
10-20	5·1
Under 10	2·6

In many of the worst cases the chief disease was *fusarium* (dry rot) which at any rate does not prevent germination.

But, on the whole, these figures show in what a bad condition is the seed planted in a large proportion of cases. 61·5 per cent. of the cultivators were using seed of which less than 80 per cent. was sound, healthy and capable of germination.

Leaving on one side at present the question of dry rot (*fusarium*) it will be seen that the principal diseases which spoil the seed are, as has already been stated, the potato moth (*Phthorimea operculella*) and the *bangdi* or ring disease.

The potato moth attacks the potatoes when in the field they are exposed owing to inadequate earthing up, and after digging, whether they are in the field or in the store. We will describe the work and its effect, both elsewhere and as it affects our areas, in the next section, but it may be said that when it occurs and the caterpillar has been working in the tuber, the germinating power is lost. The eggs, in fact, are laid in the eyes, and the young caterpillars destroy the germinating power even before they have seriously harmed the potato from an edible point of view. If no special precautions are taken the extent of attack in the storage of seed potatoes may be very large indeed. An attack of 75 to 80 per cent. of the tubers is not unknown, and the people in the Khed area estimate the average damage at ten to fifteen per cent.

The *bangdi* or ring disease, though not so important as the moth attack when the latter was unchecked, is much more difficult to deal with and is, on the average, perhaps the greatest source of loss so far as germination is concerned and during the growth. We will deal with the subject separately, but the cultivators were unanimously of opinion that the principal source of loss by ring disease is by using diseased seed. If the seed is far advanced in the disease, germination does not occur,—if it is only just begun, then the plant will die in the field after a month or two. It can, from the experience of the people, only be checked by the use of Italian seed, or seed carefully bred so as to be free from the disease.

Another possible source of loss of plants in the field, is the planting of potatoes at an unsuitable time of the year. There are two main crops in the Poona district, as has already been described, but the times during which these can be planted has not hitherto been very exactly defined. Generally it may be said that the *rabi* crop may be planted if *rutu* seed is available (which is not usually the case) from October in the Khed taluka, but that the latter half of November is considered to be the best time. Planting may go on up to the latter half of January, but after this date it is too late. Experiments as to the latest date were made at Chakan in 1920 with excellent seed imported from Italy. The seed planted on January 19th gave a yield of eleven times the seed used. From this date the yield with the later planted seed went steadily down, and that planted on February 10th only gave a yield of twice the seed used. In seed planted on the Deccan on March 1st, no crop was obtained. This is caused, as will be seen, by the rotting of the sets used in the hot soil, and by the very intense attack of the *tambera* disease if the potato crop is in the land in April and May. These dates apply to the Italian potatoes usually grown. All other English and exotic types were far more sensitive and failed when planted earlier.

The *kharif* crop is usually planted in June, but may be and is planted earlier (in May) in certain villages, notably in Pabal (Sirur taluka, Poona district). But to do this very special precautions have to be taken. The land must first be flooded with water, then allowed to dry until it can be worked and brought up to a good tilth. This watering is, we believe, largely given for the purpose of reducing the temperature of the land so as to render it fit for potato planting as the maximum shade temperature in May is often nearly 100° F. Then the sets are planted and watering follows immediately.

The other causes of low yield, namely, the very prevalent field diseases like *tambera* and rhizoctonia blight, which

affect the *kharif* crop in particular, will be dealt with in their place.

V.—THE POTATO MOTH.

By R. S. Kasargode, L.Ag., and S. D. Nagpurkar, B.Ag.

Inasmuch as the potato moth is considered by the people to be perhaps their worst enemy and as it is a very generally widespread pest over many of the potato growing regions of the world, a special account of the insect drawn from all these sources, and of the work done against it elsewhere and its application to our areas, may be of some advantage.

The potato tuber moth (*Phthorimea operculella*) is very widespread in the potato growing regions of the world.* It is a destructive pest of potatoes in the Mediterranean, in the United States and in India.† In America it is considered the worst potato pest in California, and from there it has spread into surrounding states, including Texas.‡ In Australia it is considered the most troublesome pest all over the country,§ and it was in Tasmania that it was first noticed. In India it "has spread over Bombay, the Nilgiris, the Central Provinces and as far east as Patna".† In the south of India it occurs in all potato growing districts up to an elevation of 6,000 feet.¶ There is a suspicion among the people in Khed that it was introduced here in Italian seed, but whether or not, it is generally established here now.

In connection with its introduction into our areas, it is important to note that the people themselves in the Khed area here never had any doubt that it came as the result of using

* The most recent and complete account is by Graf in U. S. Department of Agriculture, Bulletin No. 427 (1917).

† Lefroy—Indian Insect Life.

‡ U. S. Farmers' Bulletin 557 (1913).

§ Steward—Rept. Aust. Ass. Adv. Sci. 1913.

¶ Fletcher—Some South Indian Insects, Madras, 1914.

Italian seed. In the early part of 1907 the late Mr. Dixon* after a visit to the Khed villages reported as follows :—" The story of the Khed cultivators was that the potato worm came to their notice for the first time about ten years ago after they had received, from the Department of Agriculture, European potatoes for sowing in the taluka. The Junnar cultivators stated that they also had received for sowing purposes European potatoes from the Department of Agriculture fully ten years ago, but added that the potato worm only attracted their attention six or seven years ago." In 1907 the pest, according to Mr. Dixon, occurred in every potato growing village of this area.

Mr. Dixon made inquiries also, in the same year, about the matter in Northern Gujarat and reported as follows† :—" The Deesa cultivators stated that the potato worm attracted their attention for the first time about six years ago. From that time they gave up the Poona potatoes and began to import Italian potatoes direct from Bombay regularly every year. The men added that over three years ago the worm appeared again and the pest was so bad that the damage done to the potatoes varied between fifty and seventy-five per cent..... The statement of Ahmedabad cultivators was that they saw the potato worm for the first time about seven years ago and added that about four years ago the pest was so destructive that their losses amounted to fully fifty per cent..... The potato worm has been known to the Bombay merchants for the last eight years."

There is thus very strong evidence to show that the pest is a recent one and that it was introduced with Mediterranean seed, obtained to counteract the effect of the *bangdi* or ring disease.

The caterpillar attacks growing potato plants, feeding on the leaves by mining into them, and similarly affects

* Report, dated April 2nd, 1907.

† Report, dated May 28th, 1907.

tomato, brinjal and tobacco* in America, though not in India,—but on none of these is the injury serious at this time. The serious character of the pest is determined by the fact that the moth lays its eggs on the potato tuber, in the cavities containing the eye buds, either while the tubers are still in the ground but exposed, or after they are dug up and exposed either in the heaps in the field or in the store. When eggs are laid in the eyes of the potato, on hatching, after a very few days, the caterpillars penetrate the potato (incidentally destroying the germinating capacity of the eye bud) and feed inside the potato, forming regular burrows which are filled with refuse, while the potato becomes uneatable. The presence of the caterpillar in the potato can be seen by the presence of excrement on the outside. It forms its pupa inside the potato or on the outside, and the moth comes out about a month after the eggs were originally laid, at any rate in the hot weather of the Deccan.

The actual length of time in the hot weather at Belgaum required for each stage of the life history of the insect was determined by us in 1910-11 as follows :—

Egg stage (on the potato tuber) ..	6 days.
Larval (caterpillar) stage (inside the potato tuber) ..	28 days.
Pupal stage (inside or on the potato tuber) ..	12 days.

Each female moth lays from twenty-five to twenty-nine eggs.

The insect is, therefore, obviously a pest of stored potatoes. If good seed is used, and the potatoes during growth are well covered up, it affects the growing crop practically not at all. But when the potatoes are stored, enormous damage may be done. In Khed and elsewhere in Western India the chief trouble has been to preserve the seed potatoes, for

* In America it has also been found on *Solanum torvum, Solanum verbascifolium, Solanum canadense, Solanum nigrum, Physalis peruviana, Physalodes, Datura stramonium.*

the crop is sold off as soon as possible after reaping, and the preservation of it afterwards is a matter, the people think, rather for the merchant than for them. The difficulty of storing for seed, however, touches them closely, especially as cases have been known where as much as 75 to 80 per cent. of the stored potatoes have been spoilt. Of course it is obvious that the price of the whole crop must be lowered by the loss which the moth is liable to cause, and hence, though a method of storage free from moth for the whole crop is required,—the most urgent need is for a method of keeping the potatoes stored for seed free from moth.

This has been felt elsewhere in India, and experiments have been made and recorded in Pusa, the Central Provinces, and particularly in and near Patna as to the best method to adopt to secure this.

A. In Pusa* the attempt was to ascertain the best material to use to cover the stored potatoes so as absolutely to prevent the pest laying its eggs on them. The conclusions were that the best way of storing potatoes so as to save them from moth was to keep them spread out in thin layers in sand, or in sand mixed with naphthalene, or in charcoal. To store in ashes was fatal: all the tubers quickly dried up and perished. In any case from the point of view of keeping the potatoes from rot, it was better to spread them out in thin layers than to heap them in bags or baskets. Again, dipping the potatoes in lead arsenate, in crude oil emulsion, and in copper sulphate all prevented moth attack almost completely. Some of these methods could not obviously be used on a large scale, but others seem decidedly applicable.

B. In the Central Provinces the method recommended and adopted for storing *seed* potatoes, is to dip them in crude oil emulsion solution, and then store in baskets under sand. The actual process was to mix $1\frac{1}{4}$ lbs. of crude oil emulsion as bought in Bombay with four gallons of water and

* Agricultural Journal of India, Vol. V, page 20 (1910).

stir. The selected seed potatoes were then dipped for five minutes and then stored in baskets under sand. The potatoes were stored for periods up to 4½ months, and were then found quite free from moth. The amount of rotting from other sources was considerable, but the method seemed quite satisfactory as a preventive of moth.

C. An extensive and long continued series of experiments have been made by Woodhouse and Dutt at Patna, on storage in sand.

The period for which potatoes are stored in Patna is obviously much longer than with us where seed is practically never kept more than two or three months at the longest, and where potatoes grown in the *kharif* season are used for the *rabi* crop and those grown in the *rabi* season for the *kharif* crop. In Patna, however, the method of dipping in crude oil emulsion as a protection against moth was a failure and led to more rotting of the tubers than was the case without it. The system of storing under sand has, however, been a great success, and extended so far that five years after the introduction of the method no less than 186,000 maunds (6,500 tons) were stored by this method in 1914. The actual instructions issued to the people in the province were as follows :—

(1) As a preventive measure the ridges in the potato field should be made fairly wide, not less than a foot, so that the chances of tubers being exposed.........may be minimised.

(2) As soon as the harvested potatoes are fairly air dried, the affected tubers and the bruised and cut tubers should be removed.

(3) The healthy tubers should then be stored in a godown preferably on a high *machan* (platform). Cloths should be spread over the platform with one inch of dry river sand, and then the potatoes to a depth not more than a foot. All should then be covered with dry sand so that no

tubers can be seen through the sand. After a month they should be taken out of the sand and the damaged tubers removed. As soon as moths disappear from the godown the heap should be left exposed but a watch should be kept for the moth, and if it appears the potatoes should be at once covered.

(4) Storing should not be done in a hot dry godown, owing to loss by driage.

(5) Insect-affected or rotten tubers should be burnt or buried underground.

If these instructions are carried out it is stated that 60 per cent. of the weight of the stored potatoes will be found good at the end of the season.*

Such is an account of what has been done to pervent damage to potatoes, and to seed potatoes in particular in other parts of India. Outside this country reliance has been placed chiefly not on dipping of the potatoes or simply on storing them so that the moth cannot get at them, but on fumigating the potatoes coupled with clean cultivation so that the weeds on which the insect lives may not be present. In America† the recommendations which seem to have been effective are as follows :—

(1) " The first measure consists in the use of clean methods of cultivation. This implies that all infested potato plants and solanaceous weeds such as ground cherry, bull nettle, horse nettle, and volunteer potato plants growing in the same vicinity as the potatoes, must be destroyed. This can be done by prompt burning as soon as insect infection is manifest. The burning of these weeds will eliminate places for the breeding of the insect or for its successful hibernation. Domestic animals, such as sheep and hogs, are valuable for the destruction of remnants and may be utilised by merely turning them into the field."

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* Woodhouse and Dutt—Bengal Agricultural Journal, April 1911 (page 188); January 1912 (page 146).

Bihar Agricultural Journal, Vol. I (1913), page 115 ; Vol. II (1914), page 48 ; Vol. III (1915), page 69.

† See Farmers' Bulletins Nos. 557 (1913); U. S. Bureau of Entomology, Circular No. 162 (1912).

(2) The potato crop should be alternated with other crops not attacked by these insects.

(3) Dug potatoes either whole or cut should on no account be left in the field.

(4) The tubers should be fumigated with bisulphide of carbon or hydrocyanic acid gas. With bisulphide of carbon, three pounds for 1,000 cubic feet of space should be used, and the potatoes left exposed to it for 24 hours in a closed vessel, barrel or box. By this means all the moths, in every stage, are considered to be killed.

With hydrocyanic acid gas a special chamber is needed, as the gas is very poisonous, but the fumigation is more effective than with other materials and the potatoes are not damaged.

In Australia, the pest has been dealt with by fumigation and carbon bisulphide is preferred to all other materials, for the purpose. The strength required is stated to be as follows :—

(1) For the caterpillars—15 to 16 hours with 1 to 2 pounds of carbon bisulphide per 1,000 cubic feet.

(2) For the pupa—48 hours at the above strength, and it is then not always successful.

(3) For the eggs—48 hours at the above strength, and a second treatment may be needed after six days.*

So much for methods used elsewhere. In the Khed taluka the difficulty has been felt exceedingly. For fear of the moth (and of rotting, of which more later) the main crop of potatoes is sold as soon after harvesting as possible, and only enough is retained as is required either for seed or for exchanging with another cultivator for seed. The importance of earthing up the potatoes in the field is recognized by the better cultivators,—but the question of storage against the moth has hitherto been an unsolved problem so far as the people are concerned.

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* Steward—Report Austral. Ass. Adv. Sci., Vol. 14 (1913).

To show clearly and emphasise the importance of the fact in this area, we may quote an unpublished note by Mr. Keatinge written in 1909 since which time the pest has certainly not been getting less serious. Mr. Keatinge then wrote "All over the Khed taluka the potato growers complain greatly of the borer and say that it does greater damage every year. Almost every *bagayat* village complains of the thousands of rupees worth of damage since the rains,* and many individuals complain of hundreds and even thousands of rupees lost. From what I have seen I do not think that they exaggerate. I have seen many potato stores. Most of them are half ruined and some are absolutely ruined, the potatoes being reduced to a rotten mass swarming with worms. On all sides it is said that it hardly pays to grow potatoes now owing to this pest, and many are talking of giving it up........ I find that many persons know that the worms come from the eggs that the moth lays, and they have tried to prevent the moth from getting at the potatoes by putting them in pits covered with earth, and by covering up the heaps with teak leaves, and throwing water over them every day. The first plan is very unsuccessful, and I have seen such pits of rotten potatoes,—but the second plan seems to afford some small relief."

The actual method of storage in vogue at Khed is as follows :—The potatoes are harvested before the plants turn yellow and the potatoes turned up by the first ploughing are alone taken for storage. The remainder, the green coloured potatoes, and those spoilt in any way are put together and sold at once. Then the potatoes to be stored are heaped in a flat dug out area which is specially prepared for the purpose. This is usually ten feet long, five feet wide and eighteen inches deep, and it is dug either under a roof or under the shade of a tree. It is first filled with water, the water

* This note was written in December.

allowed to soak away, and then the space allowed to dry for five days. Then the sorted potatoes are heaped upon it generally to a depth of three to three and a half feet, but sometimes as deep as four to five feet, and covered with a thick layer of grass or broad leaves. Then a ditch is dug round the heap at one or two feet disance, and this is occasionally filled with water. Sometimes, though not usually, the heap is splashed with water. Such a heap, which may remain up to three months, is very carefully tended. No one is allowed to open it on any pretext, as this is considered to be very injurious.

When moth gets into such a heap it does enormous damage, and the people are helpless. The only things they have tried have been to put *neem* (*Melia indica*) leaves into the heap,— and to put sugar on the heap to attract ants which were supposed to attack and eat the caterpillars.

A considerable number of experiments on the potato moth, and particularly on the storage of potatoes so as to avoid the moth have been carried out in Western India at Belgaum, at Dharwar, in the Khed taluka, from 1906 onward, the result of which we may shortly summarise.

(1) In 1906 at Belgaum* it was shown that the potatoes as harvested were free from moth, that steeping in 1 per cent. copper sulphate solution reduced attack by more than half, but if the copper solution was washed off after treatment the tubers were attacked more than ever.

(2) In 1907-1908 at Belgaum† it was definitely proved that the use of seed attacked with moth, provided it will germinate, does not in any way lead to moth attack in the crop, and that grubs once buried in the ground along with the potatoes die in them and never from moths. The importance of earthing

* Dharwar Experimental Farm Report, 1906-07.

† Dharwar Experimental Farm Report, 1907-08, 1908-09, 1909-10.

up in the field to prevent attack there was also clearly demonstrated.

(3) In 1913-16 in the Khed taluka careful experiments were made by Kogekar on the storage of potatoes, the results of which we are allowed to quote, though they have not been yet published. Fumigation with petrol vapour was found to be a complete preventive of moth provided the potatoes were afterwards stored either on racks in airy rooms where moths could not get at them or under sand, or even in bags.

It will be seen from these accounts that the actual prevention of moth attack seems to present no difficulty in theory. If the potatoes are earthed up in the field, are rapidly taken away after lifting, and are stored where the moth cannot get at them, whether on racks in a moth proof room, or under sand, or in bags, the moth danger ceases. If the potatoes are attacked, careful fumigation with petrol vapour, while not completely eradicating the moth, almost does this and on storage afterwards there is no appreciable attack.

But a practical difficulty at once comes in. If the potatoes are stored under conditions protected from moth, whether under sand, or on racks in a moth proof room, or in bags, the percentage of potatoes rotting from other causes is so great that the method fails on this account. As a practical method the only alternative in the Khed area to the field method of storage described above is to keep the potatoes in bags, and this led to very large losses (even up to 58·8 per cent. in one case) from various rots, even after the moth had been got rid of by fumigation.

The method of fumigation had therefore not become used at all until 1917 when we undertook further inquiry with the storage of potatoes on behalf of the cultivators. Our experiments against potato moth were carried out with the full co-operation of the cultivators and a large group of men from each of four or five of the important potato growing villages gave every assistance. They were, however, quite

unwilling to consider any experiment which involved dipping the seed potatoes before storage, or which involved storing in buildings on shelves in sand. In the last case they said that the method would involve more space and more cost than they would be able to afford. The method of fumigation seemed much more likely to succeed, and potatoes were placed at our disposal for the purpose.

Previous experiments which we had conducted had shown (as already noted) that fumigation of potatoes by petrol vapour while not effective in killing quite all the eggs and pupae of the moths, yet, when selected potatoes were used, was quite sufficient to reduce the amount of moth in the potatoes to very small dimensions. In India any method depending on carbon bisulphide is almost inadmissible; the material is very dear, its use is difficult and dangerous, its carriage is only made under considerable restriction. Petrol is, on the other hand, comparatively cheap, and though not quite completely effective, its vapour is very valuable with the larva at any rate, and to a certain extent with the pupa but not with the eggs.

It was essential too that the fumigated potatoes should be stored in bags. This seems to be fatal in Bihar, and has given rise to difficulties in Belgaum and Dharwar as well as in Khed, through rotting. But unless it can be done, the fumigation, under the conditions of the Khed taluka did not appear likely to succeed. The basis of the method adopted was, therefore, the fumigation of carefully selected potatoes coupled with after storage in bags. The success of the method has been considerable, in spite of the rotting difficulty, which we have been able to deal with to a large extent. The plans employed in dealing with the rotting will be described in the chapter on potato storage.

The fumigation itself of potatoes intended for seed has now become an established practice in a number of leading villages in the Khed potato tract, and per-

manent fumigation chambers have been established in the charge of a village committee in these centres. The fumigation chambers are built of brick, cemented inside to make them gas tight, and are seven feet in internal diameter and six feet deep. The bottom is paved with Shahabad stone. Each will contain about two and a half tons of potatoes in bags. The top of the wall, all round, has a depression in which water can be placed, so as to form a water seal, which is gas tight, when the cover is put on. The cover is either made of iron, or of wood with an iron ring to fit into the depression on the top of the wall. If this arrangement is used a very simple method of securing the gas-tightness of the fumigation chamber is obtained. The appearance of the chamber is shown in Plate I.

The bags of potatoes are put into this chamber, having been as little as possible exposed to the possibility of moth attack after digging. The potatoes are not fumigated until a fortnight after being harvested. Several tin trays containing cotton wool are placed on the bags in different parts of the chamber, and two and a half pints (50 ounces) of petrol poured over the cotton wool. The cover is then immediately put on, and the whole left for twenty-four hours. This is found sufficient to kill the moths and caterpillars, to damage the pupae if any are present so that they will either not emerge or come out only in a weak form, but it does not really affect the eggs. Hence it is important that no chance should be given for eggs to be laid on the tubers immediately before the fumigation takes place. In any case a second fumigation, ten days later, is necessary to get rid completely of the insect, but it rarely pays to give this second treatment.

After twenty-four hours the chamber is opened and the bags removed, and stored in as cool a place as possible. The question of the best conditions for this storage will be dealt with later.

VI.—THE RING DISEASE OF POTATO.

By H. H. Mann, D.Sc., and S. D. Nagpurkar, B.Ag.

If the potato moth is the enemy of the crop which gives the greatest concern to the cultivators it is very closely followed by the trouble given by the so-called *bangdi* (or ring) disease or 'bangle blight', which has been in the district for very many years, and whose prevalence was the cause of the first investigations and inquiries into the crop made in the early nineties by Cappel and Mollison. The results of that inquiry are contained in the bulletins issued by the Bombay Agricultural Department in 1892 and 1893.* These were summarised by Butler in 1903,† and we shall quote parts of the description which he gives—

> "A disease known to the native cultivators by the name of *bangdi* disease, from the appearance of a dark ring visible on sections of the substance of the potato, was brought to the notice of the Department of Land Records and Agriculture, Bombay in 1893. It affected the crop of the Khed and Junnar talukas whence the greater part for the supply for the Poona and Bombay markets is drawn. Shortly afterwards it was reported to occur elsewhere in the Poona district and in Gujarat and Mahableshwar. It was stated to have first appeared some three or four years earlier.‡ By 1893 it had been found widely distributed in India: at Bangalore, in the Nilgiris, in Bengal and all through the Bombay Presidency."

Since that time it has become well known almost everywhere in India. "In Mysore", says Coleman, "it is to be

* Cappel—Note on the Potato disease prevalent in the Poona Distri t a d elsewhere, Poona 1893.

Cappel and Mollison—Second Note on Potato disease prevalent in Poona, 1893.

† Agricultural Ledger No. 4 (1905).

‡ This is undoubtedly incorrect. The disease was of old standing by all local informatic n.

found in practically every locality where potatoes are grown. The extent of its ravages is certainly very much greater than is generally supposed."

" Not only in India," continues Butler," but in almost every country it appears to be now well recognised if we can as seems probable, identify the disease with the ' potato rot ' of America. Of this, it may be said that it attacks not only potatoes, but also many other solanaceous plants such as tomato, tobacco, brinjals (egg plants), datura and others."

It is known, as already stated, in nearly all parts of the United States except the north, in the West Indies, in Java and Sumatra, in Australia, in Rhodesia, and probably in Russia, Great Britain, France and Italy. We have recently found it, in small amount only, in seed potatoes imported direct from Italy.

The disease, as it occurs among the plants, is very striking. " The first symptoms, externally, of the disease is a ' wilting ' of the green top, which occurs suddenly. A plant may look quite well one day, show signs of fading the next day and droop on the third day. This does not occur generally throughout a field, but scattered plants every where are seen withering in the midst of green ones. The tuber is arrested in growth so that the crop where disease is severe is generally poor and composed of small tubers. Many are rotten when dug and others rot in quantity in storage. The disease appears only as the crop approaches maturity, and at first even when the discoloration of the stalk just under the surface of the soil is apparent, the blackened ring is not visible in the tubers." (Butler *loc cit*).

Describing what is almost certainly the same disease Smith* says :—

" The foliage becomes prematurely yellow and dies gradually, or wilts suddenly without loss of green . . . . . .

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* Bacteria in Plant Diseases, Vol. III, page 175 (1914).

the stems droop and shrivel when not too woody, and there is usually a decided brown stain in the vascular system in advance of the death of the external parts. The vessels of such stems are filled with enormous number of the small termo-like bacteria which are not sticky and which ooze out of the stem on cross section as a dirty white or brownish white slime. The bacteria pass up and down the stems considerably in advance of the shriveling, and the accompanying brown stain can often be seen through the younger and more translucent stems and petioles......as long brownish streaks, although the surface of these parts still appears to be normal. In good sized stocky potato plants even when the vascular system is badly diseased (browned and occupied by the bacteria) the exterior of the stem is often green and normal in appearance except the leaves and extreme tips of the growing shoots which are flabby and shriveled. In less woody plants, the branches will be shriveled or flaccid.........
In the potato plant the organisms pass down through the vascular system of the stems into the underground parts and cause an internal brown rot of the tubers. This rot of the tuber begins in the vascular system at the stem end and gradually extends to the opposite end by way of the vessels, rotting the tuber grown within and causing the appearance of dusky patches on the smooth surface in advance of any rupture of the superficial cork layer...... In tubers. .... cross sections often show the decay pretty closely restricted to the vascular ring, from which there is always a grey white or dirty white bacterial ooze. In yet earlier stages of the disease the brown stain and bacterial decay are found only in the stem end of the tuber (vascular ring) or only in the vascular bundle of the underground stem leading to the tuber, the surface of this rhizome and the whole of the attacked tuber being perfectly sound. On plants attacked with great virulence and very early no tubers are formed. The tubers on plants infected in the middle of the growing season are small and few

and are found at harvest time in all stages of decay. Often on such plants, as first noted by Dr. Halsted, tubers not larger than a pea, together with their rhizome, will be found sound superficially but brown rotted in the vascular ring : in other cases, as already noted, the entire tuber will be sound and only the rhizomes affected,—this through the whole length of its vascular system or only at the end furthest from the tubers. On the other hand when plants are attacked late in the growing season, the tubers are more numerous and larger, and the majority of them, especially if borne on long rhizomes, may escape infection or be diseased only slightly at the stem and when dug. In tubers of this sort, the rot is apt to continue after digging but exceptionally it might, perhaps, remain dormant, or nearly so until the season for planting. In plants attacked by this disease the juice of the stems will be found to have an alkaline reaction to litmus paper if examined microscopically, will be seen to be swarming with bacteria which are very easily cultivated."

Coleman,* from observation in Mysore, described the symptoms as follows :—

" The disease is readily to be recognised by the sudden wilting of the potato plants in an affected field. By wilting is meant the hanging down loosely of the leaves just as they do when the stem bearing them is cut from the roots. Usually one or two leaves first show the wilting, but within a few days the whole plant wilts down and dries up. If the tubers of an affected plant are cut through, some of them will almost certainly show a brown ring a short distance in from the surface. This ring will be found usually at least, to begin at the part where the tuber is attached to the underground stalk which bears it and to spread from that point around to the other end of the potato. In its first stages, therefore, the ring is not complete but is rather simply indicated

*The Ring Disease of Potatoes—Mysore Department, Agriculture Bulletin (Mycological Section) 1, (1909).

by a more or less distinct brownish stain in the neighbourhood of the point of attachment of the tuber.... The fact that the brown colour appears first at the point of attachment of the tuber indicates that the disease has entered at this point from the stem into the tuber. If a diseased potato be cut and squeezed slightly a series of small creamy white slimy drops are to be seen exuding along the course of the brown ring. Such a drop, if examined under the microscope is found to contain myriads of bacteria shaped like small and very short rods. If a very thin slice of such a potato is examined microscopically these tiny rods are found chiefly in the vessels of the tuber which they plug quite full. These vessels are more or less tube-like structures which help to transport the sap and food materials from one part of the plant to another. In the tuber they form a ring just a short distance in from the outer surface and it is in this ring of vessels that the disease first makes its appearance. From it the disease spreads to the rest of the potato, so that, gradually the whole potato is changed into a rotten mass."

From these descriptions the characteristic appearance of the *bangdi* disease in the plant, in the tuber, and in the stem will be realised,—and also the fact that it is caused by a bacterium which lives in the vascular tissue of both the tuber and the stems. The disease was, when first discovered, supposed to be due to a fungus by Cunningham,* who first examined it. His observations, however, were incorrect, and the bacterium, already sufficiently described, is now proved to be the cause of the disease.

This bacterium appears, according to the various authorities cited, to enter the plant from seed tubers already affected, or from soil which is infected with the organism. In the latter case it has been supposed by Smith that the plants are infected by means of eelworms living in the soil. In the former it is, of course, easy for the bacteria to pass from the diseased

* Scientific Memoirs of Medical Officers of the Army in India, Part X, 1897.

set into the plant and so into the new tubers formed. Smith noticed that it might be passed from plant to plant by the bites of insects such as the Colorado potato beetle, but this kind of inoculation must be very rare in this country, according to Coleman.

Such is the disease which though it had long existed in the Khed area, came into prominence first in the early nineties, and which spread so rapidly as to become a menace to the cultivation within a very few years.

When we first carefully examined the condition in the Khed potato area in February 1917, the *rabi* crop was on the ground, and the first thing that struck the observer was the all but universal occurrence of ring disease. Almost everywhere it was recognised as leading to enormous losses, and though less prevalent in some villages (such as Peth) than in most yet it was present even in these. Often twenty to thirty per cent. of the plants in a plot had died, and we could find instances of as much as seventy or eighty per cent. of what seemed at one time a very promising crop to be lost on account of the disease. The people at that time attributed the occurrence of the disease almost entirely to the use of infected seed, drew our attention to the fact that the disease appeared very often in patches spreading from one centre, and considered that the only way of checking it was the importation, at fairly frequent intervals, of Italian seed from Bombay.

Beyond this we could not at the time go. Since that time we have ascertained many new facts, and we feel we are in a position to recommend measures which will have the effect of materially diminishing the seriousness of the disease.

The most important point in combating this disease was to find the usual means of infection. It had been known since the investigations of Coleman (1909), that diseased seed tubers would produce diseased plants, and, moreover, that infection could also take place through infected soil. But the relative importance of these methods in actual practice

had not been determined and it was absolutely necessary to our work to find out how the disease was most frequently carried from crop to crop. In other words, if soil infection was the chief source of the disease in our fields, it would be necessary to fight the disease by keeping infected fields free from susceptible plants until the bacteria which cause the disease die out. If, on the other hand, the seed was the chief means of infection, careful attention to the seed would be the primary, and might even be the only necessary method of precaution.

The determination of these points was the object of a series of pot experiments in 1917 and 1918,* in which potatoes were grown in fresh river soil in which no infection could have occurred, and infection was introduced in the following ways :—

(1) by planting potatoes containing ring disease ;

(2) by mixing pieces of potato attacked by ring disease with the soil ;

(3) by watering the soil with water in which cut sets of potatoes attacked by ring disease had been allowed to lie for half an hour ;

(4) by inserting pieces of potato infected with ring disease in the potato sets ;

(5) by soaking the potato sets in water used to wash potatoes affected with ring-disease ;

(6) by using, as seed, tubers from a plant affected with ring-disease, but which themselves showed no sign of the disease ;

(7) by using a knife infected by cutting affected sets, to cut sound potatoes for planting.

Duplicate pots were taken in each case, but the data were consistent throughout, and have results as follows :—

* An account of these experiments was published in the Agricultural Journal of India. Vol. XIV, page 388 (1919).

(1) Where diseased potatoes (eight sets) were planted

(*a*) six sets did not germinate ;

(*b*) one set germinated, but began to wither eleven days later, and was completely dead after a week ;

(*c*) one set germinated and grew fairly well. It however produced no tubers, and after ripening the original set was found to be rotten.

(2) Where the soil was infected with fragments of infected potato. Six sets were planted, and all germinated. Seven days later one was wilting. After eleven days two plants were dead and two were wilting. A week later one more was dead, but the other affected plant was making an effort to throw out new buds. It was in vain, however, and seven days after it was dead. At this time ($4\frac{1}{2}$ weeks after planting) all were affected and either dead or dying save one plant. This latter remained apparently healthy and matured normally giving three ripe tubers. On cutting these, however, all were found showing signs of ring disease in the tuber. Infection of the soil by fragments of diseased tuber is, therefore, very fatal, and even if the plants do not die, the tubers are very likely to be diseased.

(3) Where the soil was infected by the water in which diseased potatoes had been soaked.

Five sets out of six germinated, but all died of ring disease. They were quite healthy, however, for over three weeks, and then wilted and died in rapid succession. After six weeks all were dead.

This experiment shows the extremely infective character of the water in which diseased sets have been soaked.

(4) Where the sets were infected by the insertion of fragments of diseased tubers.

The results of this method of infection showed it to be by no means so certain or so rapid as those

previously considered. Out of six plants, one died in six weeks, and two more a week later. The remainder (3) ripened and were harvested in due course three months after. Of the tubers produced, those from one plant all showed signs of ring disease, from a second all showed signs except one and in this none could be detected, while in the third no ring disease could be observed in any of the tubers produced.

(5) Where the sets were infected by soaking in the water in which diseased potatoes had been placed.

In this case all the potatoes germinated normally. The first sign of disease was observed twenty-four days later, but the progress was very rapid and all were dead thirty-six days after planting.

(6) Where the sets were from infected plants, but themselves showed no signs of ring disease.

Out of eight such sets planted two died of ring disease five weeks after planting. The remainder were harvested but all the tubers produced showed signs of ring disease. This experiment showed clearly that the potatoes which were obtained from ring-disease affected plants but showed themselves no sign of the disease were unsafe as seed.

(7) Where the sets, though healthy were cut with a knife previously used to cut a potato affected with ring disease.

Fifteen healthy potato sets were planted their only connection with the disease being that the knife used for cutting them had previously been used to cut diseased potatoes. Fourteen sets germinated in due course and in good time. A month later five of them were dead, and gradually all died before maturity except two. These two matured, but all the tubers on them were half rotted with ring disease when they were taken out.

This experiment shows the extreme infectiveness of the disease.

The position is, therefore, clear. The ring disease is extremely infectious and may be carried by diseased sets or by anything which has been in contact with them. The soil may carry the disease whether it has been infected by diseased tubers, by water in which diseased tubers have been washed, or by remnants of diseased potato plants remaining in the soil. And even the knives used for cutting a few diseased tubers may infect a large part of a crop, when the seed is otherwise of good quality. This last fact is beginning now to be realised by the cultivators, and we have introduced a system of sterilizing the knives used to cut diseased potatoes, among the more advanced cultivators of the Poona potato tract.

Perhaps the chief interest, however, lies in the infection through the soil, and the length of time during which the bacteria are capable of living there, and infecting the following crop. It is obvious that if the organism is capable of making soil infective for a long period potato cultivation is doomed in these districts. We have hence made experiments to ascertain how soon potatoes can again be safely grown after the soil is thoroughly infected with the disease.

Pots were taken in which all the plants had died through soil infection with water in which diseased sets had been soaked but from which all remnants of diseased plants were removed. Then new healthy sets were planted (1) immediately, (2) after two to three months and (3) after about six months. In the meantime the soil was allowed to stand without cultivation.

Where healthy potato sets were planted immediately after the removal of the previous (diseased) crop, all the plants were affected ; out of four plants one died within three weeks of planting, another within four weeks while a month later a third was dead. The fourth was attacked, but was able

to throw out new shoots and came to maturity. No tubers were however formed. In this case, therefore, all plants were affected.

The soil from which the last crop was harvested was then allowed to stand for two and a half months (November 1st to January 18th) and then replanted. Four plants were obtained. Three remained healthy throughout, produced good tubers which showed no sign of ring disease. The fourth plant began to droop after three months and was then dug up. Of the three potatoes produced by this plant, two were apparently healthy, but the third was undoubtedly attacked with ring disease.

The same pot was again sown a week later (eleven months after the original infection), the plants matured healthily and the tubers showed no sign of ring disease.

In a further experiment, the soil was thoroughly infected with diseased material and healthy sets planted immediately. All died in due course, and then, after removal of the plant residues, the soil was allowed to stand for five months without a crop (August 18th to January 18th). It was then planted with healthy sets. Under these circumstances all the sets germinated perfectly, grew healthily and ripened normally. No tuber or plant showed any sign of ring disease.

As this matter appeared very important the experiment was repeated with no less than nine pots in all of which the soil was thoroughly infected as shown by the complete loss of the previous crop. In each case, after removal of the plants, the soil was allowed to stand for 6½ months (September 11th to March 27th) and then planted with healthy sets. All germinated and no sign of ring disease was found throughout growth. None of the tubers produced were infected with ring disease.

In summary, we may say that these experiments confirm previous results as to the conveyance of the ring disease of potatoes from crop to crop both through the seed and the

soil. They show the extremely infectious character of the disease in that not only the seed but also everything which has been in contact with it, even the knife by which diseased sets have been cut, are capable of conveying the disease to a healthy tuber and hence to a healthy plant.

The infection does not, however, live long in the soil in a virulent enough condition to affect new plants. After two and a half months the infectiveness was reduced by at least seventy-five per cent. After five to six and a half months the infectiveness of the soil has disappeared.* It would appear clear, therefore, that if land is kept free from potato plants, or other plants, like tobacco, capable of carrying the disease, for six months, the danger of infection through the soil is very small, if, indeed, it is not entirely eliminated. Inasmuch as the potato crop, usually reaped in February or March, is never planted on the same land until October or November, and the crop reaped in September or October is never planted on the same land until the following June, it would appear that the danger of infection through the soil under Deccan conditions is small, if the diseased plants are carefully removed in each crop. This agrees with practical experience and enables attention to be focussed on the provision of disease-free seed as the main line of the attack on this very fatal disease.

Disease free seed did not exist in the Bombay Presidency when these experiments were initiated: whenever seed was obtained from, it was infected to a greater or less extent. This being the case, there were only two methods open to us to secure it. The first of these was that of continually renewing the seed used by import from the country of origin,—in this case Italy. The other was by selecting the apparently healthy potatoes from any supply of seed, and growing them for several generations with strict field elimination of all infected plants in each generation.

* As against this, Butler reports that five years are considered as necessary in America to remove the infectiveness of the bacterial wilt of tobacco caused by the same organism.

The first of these methods was that adopted by the cultivators twenty years ago and since that time Italian white round potatoes, at that time imported for food, were found to be a very suitable variety for growing in the Deccan, where the thin skinned ordinary potatoes of northern India have never flourished. They were, moreover, found to be almost if not absolutely free from the ring disease, and hence gave security for several generations of crop. It became, therefore, the custom among good cultivators to obtain new Italian seed every fourth year or so, and a regular trade in seed potatoes developed. Then came the war in 1914, and the trade stopped. No more potato seed could be obtained and the crop grown rapidly deteriorated, because the seed became more and more infected.

We may draw attention, however, to the fact that judging from our experience in 1920 the seed from Italy is not *entirely* free from the disease. Seed obtained in January 1920 was planted by a number of cultivators on land which had not borne potatoes for several years. In cutting the potatoes, it was reported to us that tubers affected with ring disease had been found, and in the fields themselves we saw a few plants only which had undoubtedly died of this affection. The incidence of the attack was not more than 0·05 per cent. and so the affection in the seed must have been very small. But it is there, and it must not be considered that the use of Italian seed forms a means of completely guarding against it under the very favourable conditions which prevail here for its development.*

In the absence of fresh exotic practically disease free seed, it became necessary to see whether good seed could not be obtained locally by selection alone from existing seed, or by selection and growing of the seed, with field elimination

* It has been suggested that potato seed imported from Italy is resistant to ring disease and that it loses its resisting power after having been grown in the Deccan (*vide* Proceedings of Mycological Conference, Pusa, 1919). There is, however, *no* evidence that this is the case, and we have never had the slightest difficulty in infecting fresh Italian seed and, as a matter of fact, it is exceedingly susceptible.

of diseased plants—and a good deal has been done in these directions.

In the first place, it was important to see what can be done by mere careful selection of the seed. Ring disease, though the work of an internal parasite, can be detected, though with some difficulty, without cutting the tuber. The signs of attack, when this latter is in an advanced stage, are very marked. The eyes become dark in colour, have a "drawn-in" appearance, and drops of slimy liquid exude from them. Hence the name of "sore eyes" given to the disease in some parts of the world. But long before the disease reaches this condition its presence in the tuber can be detected by the following signs :—

(*a*) The surface of the tuber just round the eyes takes on a peculiar darkened appearance. This may be noticed all over the tubers or round certain eyes only, and is specially seen round the eye at the end of the tuber furthest from the stem. This darkening is not noticed except on careful observation and many even among the cultivators have never seen it. But we have succeeded in training women employed in sorting seed potatoes, to recognise it at once and easily.

(*b*) The scale leaves in the eyes turn dark and appear dry. This again only appears to certain eyes, and demands nice observation unless attention is specially concentrated upon it.

(*c*) The eyes as a whole have a drawn in appearance, but this appears only to those eyes in the portion of the tuber where the vascular tissue is affected.

(*d*) The skin of the potato loses its fresh appearance and becomes dull.

Using all these methods of examination, a large portion of the ring diseased potatoes, can be eliminated. In one case where sorting was done very carefully in a badly infected lot

of tubers, out of *one ton* of potatoes the following quantities were picked out :—

(1) By sorting one month after harvesting—813 lbs. (36 per cent.).

(2) By second sorting after storage and four months after harvesting—96 lbs. (4 per cent.).

After this, on cutting the potatoes for planting 14 lbs. of potatoes were found to be affected with ring disease and not to have been eliminated by the various sortings, or 0·6 per cent. If this were all, it would appear that selection only was capable of almost eliminating the ring disease. But, in the field itself, on growing, a further large number of plants died amounting to 13 per cent. It is not certain that all these died of ring disease, but a large proportion certainly did so. And, as a result, it is obvious that simple selection by examining the seed for the characters mentioned above, or even examination of the cut sets is not sufficient to avoid attack in the field. There are evidently a large number of potatoes which are so slightly affected that they are not detected even when planting, and yet which are capable of leading to the death of plants in the field, or (as we shall see) the perpetuation of the disease in the next generation. While, therefore, selection of seed from an infected lot will reduce the percentage of attack, the disease cannot be eliminated by this means. Probably the best that can be done by this method is to reduce the attack of ring disease to an extent indicated by the following figures, reported at Belgaum by the District Agricultural Overseer in 1918.

	Yield per acre.	Percentage of ring disease and rotting.
	lbs.	Per cent.
Dharwar Seed ..	4,200	50
Poona bazar Seed ..	5,600	30
Khed *Selected Seed* ..	8,400	5

As mere selection was not sufficient, and as importation from Italy was impossible, it only remained to see whether ring disease could be got rid of by gradual elimination by taking crop after crop, selecting the potatoes carefully each time for seed, and strictly removing all affected plants in the field. This has been done, and by this means we have obtained a stock of *pedigree seed* in five generations which is almost though still not quite, free from ring disease. The course of the production of these pedigree seed potatoes is shown in the following statements.

1. The original seed was taken from a lot of potatoes at Peth in 1917. The crop was reaped in the first week of February, and after fumigation a month later, one ton was taken out of a total of eight tons as the basis for the experiments. Careful selection was done at once, and 813 lbs. were at once rejected (36 per cent.) being obviously attacked with ring or other diseases. The rest was stored till June, and then was reselected when 96 pounds more (4 per cent.) were eliminated. On cutting before planting (on June 7th) 14 pounds (0·6 per cent.) more were found to be attacked and were rejected. All precautions were taken against infection of the remaining seed by sterilising the knives used for cutting the sets, in boiling water after every suspicious potato had been cut, and by insisting on all labourers who handled them washing their hands with hot water and soap before touching other potatoes.

Thus before planting 40·6 per cent. of the potatoes were rejected. In the field 10,472 plants died out of 80,000 or 13 per cent. The sets were planted twelve inches apart, so as to leave plenty of space for growth. All the deaths were not due to ring disease. Many dying from *rhizoctonia* blight and other diseases. The remainder were reaped on September 8th, 1917.

2. The seed so obtained was fumigated three weeks later and selected as before. From 3,000 pounds of potatoes we obtained :—

(*a*) First selection—217 lbs. of ring-diseased potatoes (7·2 per cent.).

(*b*) Second selection before and at planting 67 lbs. of ring-diseased potatoes (2·2 per cent.).

One ton of seed potatoes were planted (at Chakan) on December 15th, and from this 5,730 plants died or 7 per cent. The remainder were harvested on March 20th, 1918.

3. The seed so obtained was fumigated and then kept till the following October. After fumigation, the ring-diseased potatoes were removed amounting to 67 lbs. out of 3,000 lbs. or 2·2 per cent. A second sorting in July was made giving 10 lbs. more of rejection (0·3 per cent.) and a third sorting at the beginning of October gave 19 lbs. (0·6 per cent.) or a total of 106 lbs. or 3·1 per cent. During the storage period there was a good deal of dry rot (*fusarium*) but this was not taken into consideration in the present case.

One ton of seed potatoes were planted (October 3, 1918) at Awasari and at the time of planting 6 lbs. (0·3 per cent.) of the potatoes were rejected. During the growing period 2,722 plants or 3·4 per cent. died and were removed. Harvesting took place on January 14th, 1919.

4. The seed so obtained was fumigated, sorted, bagged and stored till June 1919. At the first sorting 6 lbs. (0·2 per cent.) were rejected out of 3,000 lbs. of tubers, on account of ring disease at the second selection 20 lbs. more (0·7 per cent.) were removed and at the time of planting 4 lbs. more (0·1 per cent.) were taken out. The total percentage removed between harvest and replanting was 1·0 per cent.

One ton were again planted (at Peth) in June. Owing to an unsuitable field being chosen many plants died of rhizoctonia blight. But only 196 plants (out of 80,000) or

0·24 per cent. were definitely killed by ring disease. The crop was harvested in September.

5. Similar figures for the next crop are as follows :—

(*a*) 3,000 lbs. of seed on all sortings up to planting time gave 26 pounds of ring-diseased potato (0·9 per cent.).

(*b*) one ton of seed, at the time of planting at Pargaon, gave 13 ring-diseased potatoes (about 3 lbs. or 0·1 per cent.).

(*c*) During growth between November 1919 and February 1920, 46 plants died fron ring disease or 0·1 per cent. As we write, the plants are in store for planting in June 1920.

The whole history can be summarised in the following table * :—

Generation.	Disease on 1st sorting.	Disease on 2nd sorting.	Disease on 3rd sorting.	Disease at time of planting.	Ring disease in field.	Total, Ring disease.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I ..	36	4	....	0.6	13	53·6
II ..	7·2	2·2†	....	....	7	16·4
III ..	2·2	0·3	0·6	0·3	3·4	6·8
IV ..	0·2	0·7	....	0·1	0·2	1·2
V ..	–	0·9	....	0·1	0·1	1·1

* In the first crop the rejections include all diseased potatoes : in the later ones only ring-diseased potatoes or plants are considered.

† All rejections up to planting.

In five generations, therefore, the amount of attack with ring disease has been reduced to a very small proportion and this can doubtless be carried further. And this method therefore reveals clearly the way in which a stock of acclimatised seed can be maintained which is not seriously affected with ring disease. It is only necessary to grow the stock under conditions of rigid elimination of all affected potatoes and of all affected plants at every stage, and the fear of the disease will disappear. The seed so produced will be far cheaper than that imported from Italy, and will be independent of any failure of the latter supply. It seems, in

fact, that the maintenance of a stock of pedigree seed is the only practicable way by which ring disease now rampant in our potato areas, can be gradually eliminated, or at any rate, kept under control.

The principal points of practical importance which emerge from this discussion of our experiments on ring disease are as follows :—

1. Under the conditions which prevail in the Poona district and probably also in other parts of Western India, ring disease is almost exclusively carried by seed. Although the soil may be a source of infection, yet the disease quickly dies out in it, and six months after infection it ceases to be a serious source of disease.

2. Every diseased tuber or diseased plant is, however, a very powerful source of infection as the bacteria are extremely virulent. Hence every plant which dies in the field should be immediately removed, together with all tubers and roots attached to it, and buried deep. After harvesting careful selection of the tubers should be made among all that may be used for seed and the affected potatoes sold at once. Fresh selection should be done before seed is taken to the field for planting.

3. At planting, the sets, on being cut, should be carefully examined for the signs of disease, and all diseased sets rigidly excluded. The man who is cutting and examining the sets should be provided with boiling water and the knife used for cutting a diseased set should be sterilised in this boiling water before being used to cut others. This method is now actually adopted by some of the more advanced cultivators in the Khed potato tract.

4. The only practicable way we have found of eliminating the disease is by the use of disease-free seed, whether from abroad, or by obtaining pedigree seed by strict selection, and elimination of disease during a number of generations. We have succeeded in reducing the incidence of the disease

from 53·6 per cent.* to 1·1 per cent.† in five generations. This method gives a system whereby cheaper seed can be obtained than that bought from Italy and at the same time makes us independent of international troubles which may again at any time prevent us from being able to get seed from abroad, as has happened from 1915-1920.

5. It has been possible for the agricultural department with the assistance of the cultivators to maintain a stock of from one ton upward of such pedigree seed : multiplication beyond this point is the work of an agency working on a commercial basis. It is certain that the people will pay a good price for seed in which they have confidence.

VII.—OTHER DISEASES FOUND IN THE SEED.

BY S. D. NAGPURKAR, B.AG. AND G. S. KULKARNI, B.AG.

Our investigations of other diseases found in the seed in Western India, which may spread to the plants in the field and hence cause loss and low yield generally, have been of a somewhat casual character, but it will be well to put on record what has been noticed,—as some of these diseases are of very great importance and demand early and thorough investigation. The diseases which we have noticed in the seed in Western India are as follows :—

1. Dry rot caused by various species of *Fusarium*, and especially by *Fusarium trichothecioides* and by *Fusarium oxvsyorum*. This is universal and very prevalent.

2. *Rhizoctonia blight*.—Of this *Rhizoctonia destruens* is very common on potatoes in store, and *Rhizoctonia solani* is also found.

3. *Spongospcra subterranea, or khuzali* found only in hill-grown potatoes, chiefly at or Mahableshwar but also occurring in the Nilgiri potatoes.

4. Potato eelworm (*devi*) which is fairly common in the *kharif* grown crop of potatoes, but can hardly be called very serious pest here, except perhaps at Karachi.

* All diseases

† Ring disease only.

A Dry Rot of Potato Tubers.

Among all the diseases and troubles of potato storage, dry rot is (if we exclude the potato moth) the worst and most generally widespread in Western India. It is known to be liable to invade stored potatoes every where in the world, if they are kept under any but very cool conditions,—and cool conditions are impossible here. The most usual form of the attack is a softening of the skin at one point (generally the stem end of the tuber) with a slight depression. The skin may or may not split at this point. If it does, the hole so produced enlarges and the potato is gradually eaten up by the fungus leaving a brown residue. If it does not the potato gradually shrivels and ultimately remains as shrivelled mass of hard brown matter. These characteristics are associated with the name '*khokha*' among the cultivators in the Poona district. But the tuber which has been attacked is often also affected by bacteria which convert the diseased potato into a slimy wet mass of rottenness. There are, however, many parasites which produce ultimately this last condition and it is very difficult to state in any one case what is the primary cause of the rotting.

In the case of the *khokha* or dry rot, occurring in its typical forms, there is no difficulty in identifying it, and it occurs in every large sample of potatoes we have come across in India. To ascertain the extent to which this and other rots were contained in actual commercial samples of potatoes of different provenance, a bag of potatoes from six of the chief producing centres in India was examined in January 1918, and the potatoes then stored for two months at the usual temperature in Poona. The results of these observations are as follows :—

1. *Mettapalaiyam potatoes.*—These potatoes, though marketed at Mettapalaiyam are grown in the Nilgiris, and are hence produced under fairly temperate conditions at a considerable elevation--4,000 feet and upward.

The amount of potatoes damaged with various attacks is large, as much as 22 per cent. being rejected. In this lot dry rot was especially pronounced, some of the tubers being completely eaten up by the fungus. Many tubers were shrivelled and intact showing the dry rot fungus only. But in a good many tubers the outer covering was broken, and bacteria and moulds had entered and a soft wet rot was the result.

Some examples of *Spongospora* or potato scab (*khuzali*) were noted in these potatoes. This seems peculiar to potatoes grown in the hilly districts.

On storage in bags at the temperature in Poona in January and February (65°F. to 85°F.) the rotting rapidly increased chiefly due to 'dry rot' fungus (at any rate at the beginning) until after 51 days, 90 per cent. of the potatoes were rotten either with simple dry rot or more frequently with the soft wet rots which follow it.

2. *Kalka potatoes.*—These potatoes, again, though marketed at Kalka, are chiefly grown in the Simla hills, and are hence produced under fairly temperate conditions at 2,000 feet elevation and upward.

The amount of potatoes found damaged with various rots in the commercial lot amounted to 15 per cent. The chief form of rotting present was 'wet rot', but the original cause of the damage in most cases appeared to be the 'dry rot' fungus. In the partially damaged potatoes, most of the tubers showed the characteristic sunken wrinkled spots of this disease.

A few potatoes showed signs of damge by eelworms.

After 50 days in bags at the temperature of Poona in January and February (see above) fifty per cent. of the stock had become wholly or partially rotten. By the middle of March only 19 per cent. of the original potatoes were still good, the dry rot fungus being the original cause of damage in most cases.

3. *Meerut Potatoes.*—These potatoes are marketed at Meerut in the United Provinces, but we do not know exactly where they are grown. They showed only three per cent. of partly or wholly rotten potatoes when obtained but among these there were many potatoes attacked by the dry rot fungus and also some by ring disease. The chief rot was undoubtedly 'dry rot'. In 50 days, thirty per cent. had become wholly or partly rotten, chiefly still with the dry rot fungus.

4. *Bangalore Potatoes.*—These potatoes are grown on the Mysore plateau at an elevation ranging from 2,000 feet to about 3,500 feet above sea level. 12 per cent. of the tubers were wholly or partially damaged on receipt and although the rot caused by ring disease was found, yet the chief cause of damage again was the dry rot fungus. Fifty days later, fifty-five per cent. of the potatoes were wholly or partly rotten in Poona, in January and February.

5. *Karachi Potatoes.*—These are grown in the neighbourhood of Karachi in the tract of intensive cultivation within a few miles of that city. Though there was a good deal of dry rot in the potatoes as bought, the characteristic, attack in this case was a large amount of eelworm. Nine per cent. of the potatoes were partially or wholly rotten. The 'dry rot' and its sequels, the various forms of wet rotting, kept increasing on storage, and 25 per cent. more potatoes were wholly rotten or partially damaged after fifty days of storage.

6. *Saugor Potatoes.*—The neighbourhood of Saugor in the Central Provinces is a great place for growing *rabi* potatoes, which are then sent to Bombay. The usual dry rot attack was found and its sequels. No ring-disease potatoes were noticed, but there was a considerable amount of rotting due to moth attack. One eelworm attacked potato occurred. The amount damaged on purchase amounted to 6½ per cent.

On keeping, the attack due to dry rot fungus developed and ten per cent. additional potatoes were lost in fifty days.

Pupae of moths were also found. These potatoes have kept better than any of the other lots, examined. They are all Italian white round potatoes produced from Poona seed.

7. *Khed (Poona) Potatoes.*—Potatoes in one of the best village stores in the Poona district were examined one month after being put into storage. The quantity involved was fifty tons, and all these were carefully sorted. From this quantity five tons were rejected on account of attack by dry rot and its sequels. They were fumigated and bagged, and kept in store at a temperature below 88°F. After three months in the store they were again sorted with the following results :—

	lbs.
Rejected on account of ring disease ..	407
Rejected on account of *fusarium* in its various forms	1,960
Rejected on account of 'heat rot' ..	178
Rejected on account of unknown rots ..	840
Total ..	3,385

Thus of the total rotting, fifty-eight per cent. is due to the dry rot fungus (*fusarium*).

From this account of actual observations of potatoes on the market, it will be seen how far the 'dry rot' dominates the situation so far as keeping potatoes for seed is concerned, provided (as we shall see later) the temperature is kept within the permissible limit. We have now to consider how far the dry rot damages the tubers for seed purposes.

The dry rot of potato tubers, it seems now definitely to be proved, is caused by a species of fungus belonging to the genus fusarium, and the latest information available* seems to indicate that several species may cause the damage under different conditions, and that these also may cause a

* Link—Botanical Gazette, Vol. 62, page 169 (1917).

wilt of the potato plant in the field. Two species have been identified here,* and they are the same which appear to do the greatest damage in America. As far as is known potatoes most usually become infected through the soil. The fungus enters the plant through the roots, thence goes into the underground stems, and finally into the tubers. How far other methods of infection prevail is doubtful and so experiments were made in the following direction with Italian white round potatoes at Poona.

A.—Do potatoes attacked by dry rot (*fusarium*) infect those with which they are stored? The answer to this question has been given by McAlpine† and Link (loc cit.) in certain cases. The former found that when the skin of a tuber was broken infection was generally easy from a potato already infected and that in the case of very young potatoes where the skin was unbroken infection could still take place: the latter confirmed the first of these observations as regards both of the species of *fusarium* which are apparently concerned in the present case.

With the contention that dry rot infection can be carried from tuber to tuber by infection through cut or broken surfaces we are in agreement, and it is well known to the cultivators in the Khed potato tract. When they find a potato which is damaged at the stem end, they consider that such a potato is certain to decay in storage.

But the infection of mature potatoes with unbroken skin, has not been successful with us with Italian white round potatoes. In the case quoted McAlpine only obtained such infection with very young potatoes, and it is quite possible that the extent to which it takes place depends largely if not entirely on the thinness and delicacy of the skin of the potato tuber. The Italian white round potato with which we have worked

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* *Fusarium trichothecioides* and *Fusarium oxysporum*.

† Potato Diseases in Australia, Melbourne, 1911.

has an exceptionally thick skin and it shows much slower deterioration in storage than any others grown in India. The potatoes are in fact preferred by the cultivators not so much because they give a bigger yield in the field, but because there is less loss in storage owing to dry rot and its sequels. At any rate all the experiments in which we have attempted to infect healthy unbroken mature tubers of this variety by storage with potatoes sttacked with dry rot have failed. Whether this will apply equally to the thinner skinned varieties of northern and southern India we do not know.

B.—Do tubers, infected with *fusarium* and used as seed give rise to tubers also infected and likely to rot.

On this point there does not seem any definite information to be obtained from other authorities, but the matter is one of great importance in our areas, because (1) the people have noticed that potatoes slightly attacked with dry rot germinate more quickly than perfectly healthy tubers, which is supposed to be a great advantage and (2) the whole question of the maintenance of a satisfactory seed supply for planting is affected by the question as to whether we must necessarily reject seed potatoes which show any signs of dry rot (*khokha*) attack.

It has not, we believe, been noticed hitherto that potatoes slightly attacked with fusarium in the form of dry rot, *do* germinate quicker than ordinary sets. This was often, as already stated, mentioned to us by the people, but definite experiments were wanting. The following are the details of a recent experiment on the subject.

One hundred clean potatoes, and one hundred in which the dry rot was just developing and where the affected portion was one inch in diameter were taken, and germinated in soil. The number which had germinated after two weeks and after

three weeks was as follows. In each case the seed was four months old.

	Clean seed. Per cent.	Fusarium seed. Per cent.
(1) Germinated after two weeks..	50	89
(2) Germinated after three weeks.	80	97

The result agrees, therefore, with the contention of the cultivators.

As to whether seed potatoes slightly attacked with fusarium do lead to attack in the tuber, we have the following experiments.

1. The potatoes were grown (in 1917) in pots containing fresh river soil which had never previously borne this crop. Four sets from a slightly attacked tuber, in which the eyes appeared still quite healthy were planted. The plants grew healthily, and twelve mature potatoes were harvested, all being perfectly healthy at the time of harvest. After 15 days storage three of the largest potatoes showed signs of dry rot, and a month later four more were also affected. Two more were attacked after $2\frac{1}{2}$ months. The others remained free from disease for over three months. Thus 75 per cent. of the tubers produced from *fusarium* affected seed were attacked by dry rot during a storage of three months. Healthy potatoes in the same soil as above showed no sign of *fusarium* attack in storage.

2. A similar experiment was made in 1919, when eight sets like those in experiment No. 1 were planted and all grew healthily. Thirty-two potatoes were recovered all being healthy at the time of harvest. Out of these, nine were affected with fusarium after a month in storage, or nearly thirty per cent. of the total.

Other similar experiments gave similar results and it seems clear, therefore, that seed potatoes attacked with dry rot, while they may yield apparently healthy tubers

at harvest, yet give a very large probability of being attacked with *fusarium* at a later stage.

C.—Do potatoes become affected through the soil, or in other words does an infected soil produce tubers likely to rot? It has generally been considered that infection from the soil is the usual method, and the following experiment in pots containing river soil was designed to show what would happen with the variety in use in the Deccan. The soil was infected by incorporating thoroughly with it scrapings from potatoes suffering from dry rot. Healthy sets were planted, and at harvesting the tubers (8) collected were *all* healthy. Twenty days later one showed signs of dry rot and after three months seven tubers were diseased or 88 per cent. It will thus be seen that infecting of the plant through the soil, immediately after infection, is fairly certain.

To see whether the infection in the soil would last for some time, the pots used in the last experiment were allowed to stand for three months and were then again planted with healthy sets. These grew well, and the plants remained healthy up to maturity. At harvesting all the potatoes were sound. Twenty days later one potato was affected with dry rot. Two months after harvest, all were diseased with *fusarium*. It is evident that the soil remains completely infective for three months.

Another infected pot was kept for eight months after removal of the first crop, and was then again planted. All the potatoes were healthy at harvest, and remained healthy for three months in storage.

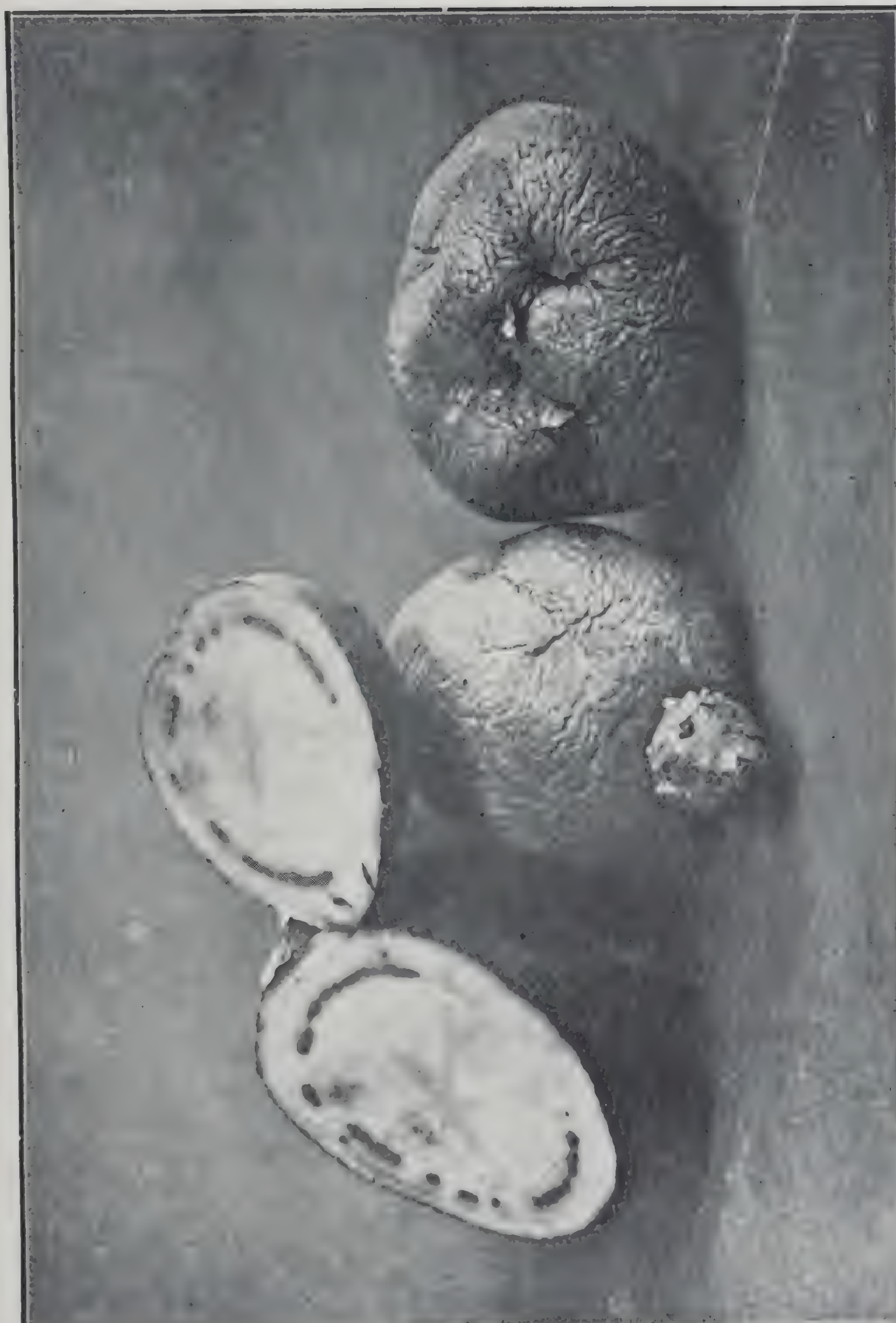
While, therefore, this experiment cannot be regarded as conclusive, yet it would indicate that infected soil will produce disease in tubers grown upon it, that the soil remains infective for three months in the dry season when no crop is growing, but that after eight months (in the dry weather) without crop, the chance of infection is very much reduced.

Wilt Disease Caused by Fusarium.—It seems clear that the rot in storage which we have now discussed is not the only way in which one or other of the species of *fusarium* may attack potatoes, and that one of the fairly frequent wilts of the crop in the field is caused by a fungus belonging to this genus. Exactly what the relationship of the rotting of the tubers to wilt in the field may be, is not yet known, but such a wilt has been observed in America and in Australia as well as here, and under the name of 'brown ring' or 'wilt disease' has been frequently described. We did not notice it here in the Deccan until recently, but the presence of a number of plants which were wilting in the fields, with a brown ring in the tubers and yet which were not affected with the bacterial ring disease already described, led us to discovery that the *fusarium* wilt of potatoes also exists here.

This fact accounts for many of the contradictory reports which we have received about crops grown with seed which we have supplied. In one case, seed was supplied and was reported to have been badly affected with ring disease. This was quite incomprehensible, especially when it was stated that eighty per cent. of a crop had died. The rings in the tubers did not however show the characteristic of true ring disease, and it now seems certain that they were produced by *fusarium* in the soil. Another recent case occurred with fresh Italian seed, planted in land which had never borne a crop of potatoes before. A number of the plants died, with a brown ring in the tubers, which under special examination by the Economic Botanist to Government (Dr. Burns) were found to be affected with a species of *fusarium*.

We have done little with this disease except to note its occurrence at the agricultural college farm, Poona (March 1919) and at Chakan and several other villages in the Khed potato tract. But we have kept potatoes from plants which

PLATE II.



Fusarium Wilt in Potato Tubers.

have died in the last stage of life and which contained a brown ring. These have been planted, in *fusarium*-free soil, have grown to maturity, and have yielded tubers which became damaged with dry rot. But of the relationship of the two forms we at present know nothing. We have planted potatoes affected with dry rot in several stages, and we have planted healthy sets in infected soil, but so far we have not succeeded in producing the *fusarium* wilt with certainty by any method. Whether the *fusarium* connected with this is a different one from that which is uasually found in the dry rot here is uncertain, but it appears unlikely in view of the work of Link (loc. cit.) and others. The whole question of the relationship of the two forms requires careful and thorough investigation at an early date.

Summarising with regard to the dry rot fungus (*fusarium*) of potato tubers and the very similar if not identical fungus which causes wilt in the field we may note as follows :—

(1) Dry rot forms by far the dominant disease of stored potatoes in India, seed potatoes from every part of the country being badly affected. In some cases, the amount present is so great that storage in Poona in the cold weather for two months at about 80°F. means the loss of over 80 per cent. of the stored potatoes.

(2) The Italian white round potato, grown in Poona and on the Deccan generally, does not rot so easily in store with this fungus as the thinner skinned kidney varieties grown in the Nilgiris, the Himalayas and North India generally.

(3) While potatoes with broken skin are infected in the store there is no evidence that mature potatoes with unbroken skin, of the Italian white round variety can be so infected, all our experiments to secure such infection have failed.

(4) *Fusarium*-infected tubers when used as seed give tubers which while apparently healthy at harvest rapidly become damaged by dry rot, and hence rapidly decay in storage.

(5) Tubers grown in infected soil, rapidly decay on storage. The soil remains infective for three months at least. After eight months, in one experiment, infection was not obtained but this cannot be regarded as conclusive.

(6) With these results, the use of infected seed, however slight the infection may be, must be regarded as perpetuating the disease, though it may not apparently give a lower yield or unhealthy plants in the field. To obtain good seed, the potatoes must also be planted in soil which has not recently borne a crop liable to this disease. Eight months is the minimum time required for soil to free itself from infection and it may need much more.

(7) *Fusarium* wilt, leading to dying of the plants in the field also occurs in the Deccan area. Its relationship to the dry rot which is so common is not known, but when a tuber from a wilted plant is grown, the tubers which are produced are rapidly attacked by what is apparently ordinary dry rot, in storage.

B.—Rhizoctonia Blight of Potatoes.

If any one visited the Khed potato tract during the time of *kharif* or rains crop is growing, and saw the very large mortality caused by the *rhizoctonia* blight in many cases, he would be inclined to consider it as the worst of the diseases affecting the potato plant in this part of Western India. The field characteristics of the disease are as follows. The plant, apparently in good condition, begins to wilt without apparent reason. The wilting commences at the lower branches, but quickly spreads until after from six

to eight days the whole of the leaves are hanging down and the plant is withering. On pulling up the plant, the lower portion of the stem is found rotten and its fibres can be easily separated from one another with the fingers. As a rule this part of the stem and root are covered with a white fungus mycelium, among which there often exist a number of brown knots or sclerotia. These fungus mycelia often spread over the rootlets and tubers, and also through the soil to adjoining plants. This last occurrence was noticed with special frequency in 1919 at Peth. The people call the disease '*buri*'.

The disease is caused by a fungus or group of fungi well known throughout the world to cause both a wilt of the potato plant in the field and a rot of the potato tuber in storage. In India, the matter of these fungi has been closely investigated by Shaw and Ajrekar, and the mode of attack has been described by them as follows :--

"As already mentioned the potato is liable to disease owing to this fungus. In Bihar the parasite has appeared chiefly as a rot of stored potato, but in the vicinity of Poona it is a frequent cause of trouble to the growing crop. The mode of attack is exactly similar to that observed in the betel vine, the portion of the stem at the ground level, and the subterranean parts of the plant becoming covered with a weft of hyphae with sclerotia. This is followed by the rooting of these parts and by the drying and browning of the leaves. The attack is usually late, about six weeks after the planting of the sets. The tubers from diseased plants are apparently sound, although smaller than those from healthy plants, but cases have been found in which apparently sound tubers from diseased plants have been infected with the mycelium through their attachment to the parent stem. The experience with stored potatoes in Bihar shows that tubers from a diseased crop are probably infected with the fungus. The use of a wash of corrosive

sublimate, combined with proper precautions in storage, would certainly go far towards lessening the disease in store.

"Inoculations of potato tubers were uniformly successful when the infection was made upon the cut surface of a tuber. In unwounded tubers although the fungus spread over the surface of the tuber, the external corky covering was sufficient in many cases to prevent penetration. Sometimes, however, penetration took place through the eyes, or even through the lenticels. The same results were obtained whether the fungus used for inoculation has been isolated from a diseased potato or from the betel vine." *

As noted by the above authors, rhizoctonia not only caused a very serious wilt in the field, but also a rot in storage. This occurs with great frequency when the tubers are stored under damp conditions, and is very common in the stores constructed by the cultivators in the field especially when covered up to avoid moth. . . . In the commonest form in the Poona district the tuber becomes first covered with mycelium, and then gradually becomes soft and watery. In no case does the skin become loose and puffed up by gas, but the portions rotting show depressions.

It must not be supposed that potatoes which carry mycelia or sclerotia in the surface, however, will inevitably become rotten. By far the larger proportion of tubers we have examined show, on incubation, signs of rhizoctonia infection. But the rotting of the potatoes depends on storage conditions. If the potatoes stored had plenty of air, and the moisture surrounding the potatoes was not allowed to increase, the danger of *rhizoctonia* rot has always been very small. And, moreover, potatoes actually produced by wilted plants did not rot on storage, provided the

* Shaw and Airekar :—The Genus Rhizoctonia in India. Mem. Depart. of Agriculture, India (Bot. Series), Vol. VII, No. 4 (1915)

PLATE III.

Rhizoctonia Destruens on a Potato Tuber.

PLATE IV.

Powdery Potato Scab, from Mahableshwar.

necessary conditions of aeration were supplied. It has been often recommended that in order to protect seed potatoes from *rhizoctonia* rot, they should be dipped before keeping in a solution of mercuric chloride (1 in 1000) or in formalin (1 per cent.). If the skin of the potatoes is unbroken and if proper aeration in the store is obtained our experiments lead us to suppose that even this is not necessary. If the necessary conditions of aeration are not obtainable, no doubt the proposed method will be of advantage.

With regard to the wilt in the field, one result is clear from all our observations. The *rhizoctonia* wilt occurs at certain seasons and in certain fields. These seasons are generally those when the soil is liable to contain excess of water. Thus the disease is essentially one of the *kharif* season so far as good land is concerned, when the rains may cause almost any field to be at times waterlogged, at any rate in the various Deccan tracts. Again, in the *rabi* season the disease is practically confined to ill-drained fields. We venture to connect, in fact, the *rhizoctonia* wilt in our areas very largely with badly drained land. The soil always contains the fungus. The half rotten manure used contains it in abundance. The potato tubers themselves also generally carry some infection with them. But all these are not sufficient to produce wilt if the field conditions are satisfactory, in point of drainage. It is in fact, in the study of the improvement of the cultural conditions, that the best hope of dealing with *rhizoctonia* wilt lies.

C.—Potato Powdery Scab.

This disease of potatoes, which has not hitherto been noticed in India as far as we can tell, and which is apparently only important in the hill districts, need not detain us long. We found it, under the name *khuzali*, as a serious blight at Mahableshwar where it occurred almost everywhere. Again in examination of potatoes from the Nilgiris we found it

frequently, and in considering the question of seed for and from these centres it must be continually kept in view as a disease of importance, and one which may, under suitable conditions, lead to a reduction in crop, and in the value of the crop reaped.

The disease is caused by a fungus, *Spongospora subterranea*,* which produces scabby spots on the potato tuber. These scabby spots "are at first raised above the general surface of the tuber, and form patches one eighth to one quarter of an inch in diameter. . . . . . The parasitic fungus literally gnaws away the surface of the tuber which in some cases resists the parasite by forming a protective layer of cork, but usually the powdery snuff-coloured spore balls are the most prominent feature. Hence the name of 'powdery potato scab' sometimes given to the disease."†

The disease seems to be almost peculiar to cooler regions, but where the climate is suitable, it is produced where affected potatoes are planted, or where healthy potatoes are planted in infected soil. When infected tubers from Mahableshwar were planted in the Poona-Khed area, no infection resulted, as the climate of the latter region was probably too warm. This is in accordance with experience elsewhere, and particularly in America. Infection, in our experiments, does not occur when the affected potatoes are stored with sound tubers.

The matter is important, however, so far as Mahableshwar and the Nilgiris are concerned. And this being so, we may say that no method of eradication has yet been found. No soil treatment will clear out the disease, though sulphur at the rate of nine hundred pounds per acre, applied broadcast, reduces the amount of infection.‡ Seed treatment

* The best account of this fungus is by Melhus, Rosenbaum, and Schultz in the Journal of Agricultural Research, Vol. VII (1916), page 213. The disease is mentioned by Butler—Fungi and Disease in Plants (Calcutta 1918)—but he does not say definitely whether he has noticed it in India.

† McAlpine—Potato Diseases in Australia (1911), page 78.

‡ Melhus, Rosenbaum, and Schultz (loc. cit.),

PLATE V.

Eelworm Disease of Potato.

with certain chemicals notably mercuric chloride or form-aldchife will reduce the disease. No resistant variety is at present known, and though early harvesting may sometimes prevent infection it cannot be relied upon. The matter obviously needs very careful further investigation in the districts (above noted) which are already affected, in order that the extension, in hill districts, of this very serious potato rot may be prevented, and it may be eradicated where it already occurs.

D.—Eelworm Disease of Potato (Devi).

During the course of our field investigations of potatoes in the Khed area we found in 1917, first at Peth, a large number of plants affected by a peculiar form of scab, which was termed '*devi*' by the cultivators, and which particularly affected the *kharif* or rains crop. This has now proved to be a widespread disease of potatoes in India, both in the field and in storage, and has been found, on careful examination, to be produced by a species of nematode or eelworm, probably identical with that which has been found to cause a similar disease in America and elsewhere.

" This disease is caused by a minute nematode worm . . which is so small as to be almost invisible to the naked eye. The mature female is nearly pearshaped . . . being less than a millimeter in length. . . The male is a slender thread like worm from 1 to 1·5 millimeter in length. The development of the female takes place within the underground tissues of the host plant, and its presence in these tissues is indicated by enlargements or malformation . . . The skin is roughened and broken in patches." * The roughened part shows small shining spots, which are very characteristic of this disease, and distinguish it from others with which

* C. S. Scofield—Nematode Eelworm on potatoes and other crop plants in Nevada, United States of America, Department of Agriculture, Bureau of Plant Indus, Circular No. 91 (1912).

it might be confused. In the field, in an advanced stage of the disease, protuberances are formed on the surface in which eelworm are found. In storage these protuberances disappear and the worms apparently invade the deeper tissues.

The eelworm which causes the disease attacks many plants, and it has been recorded on no less than five hundred of them including most garden crops, lucerne, clover, grain crops, fruit trees and weeds. The young eelworms as a rule enter the plants from the soil by the tip of the rootlet, and they also pass into the young potato tubers through the lenticels, several entering frequently at the same part. Experiments elsewhere seem to prove that they are spread by seed potatoes, and that they may be carried in irrigation water. When soil is thoroughly dried, the eelworms are apparently killed, and when potatoes are eaten by an animal, the dung of the animal is said *not* to convey infection.*

Our own experiments indicate quite conclusively that seed potatoes attacked by eelworm cause the disease in the crop produced from them, and that infection is certain even in soil which has never borne the crop before. Infection through the soil was equally certain where river soil, which had never grown potatoes, was infected by means of scrapings from eelworm-infected potatoes ; the crop grown was attacked in every case. Where a pot containing infected soil was kept for three months, the soil still remained infective, whether the pot had been watered in the meantime or not.

In storage we found that the affected potatoes rapidly become rotten, the type of rotting being a soft, but not wet, rot. The eyes were not affected, and the sprouts were actually forming after three months in storage. It is obvious that in attempting to deal with this disease, it is essential to get rid of as many of the eelworms as

* Monthly Bulletin, Comm. on Horticulture. California, Vol. V, page 60 (1916).

possible in the soil, and to use seed free from living worms. As regards the soil it has been suggested in America that anything that will lead to the drying of the ground and its exposure to the sun's rays will tend to reduce infection. Thus deeper ploughing of the land with consequent exposure of the soil to the sun's rays in hot dry weather has been recommended,—though our experiments in this direction were, we must confess ineffective. As regard the seed we have found that fumigation with petrol was quite ineffective in killing the parasite. Dipping of the potatoes in copper sulphate or formaldehyde solution have been found equally useless elsewhere. It has been suggested that slight heat will kill the eelworm, and that if seed potatoes as exposed for 24 hours to a temperature of 104°F. the parasites will die.* We have not however, tried this ourselves.

The extent of the disease in India is not known, but we have found it in all parts of Western India. As regards stored potatoes it was worst in those obtained from Karachi. The seriousness of the attack seems to vary much from year to year. Thus in 1918, it was particularly bad in the Khed tract, while there was very little in 1919. The cause of these variations is not known and demands careful further investigation.

VIII.—FIELD DISEASES OF POTATOES LEADING TO LOSS OF CROP.†

By H. H. Mann, D.Sc., S. D. Nagpurkar, B.Ag., and G. S. Kulkarni, L. Ag.

A.—The Tambera Disease of Potato.

In the Poona district the plants grown during the rainy season (the *kharif* crop) are severely affected by a peculiar

* Frandsen—Monthly Bulletin, Comm. on Horticulture, California, Vol. V, page 60 (1916).

† We deal in this Chapter with the diseases we have studied. It is stated that potatoes at Gokak are always seriously affected with tip-burn, but we have never investigated it, and do not know what is the real cause of the affection.

disease, which, on account of the reddish colour which the affected fields acquire, has been termed *tambera* by the potato cultivators. The disease only attacks the *kharif* crop to any serious extent, but of this it is by far the most serious enemy, and, in a year where it is specially prevalent, it often means that the crop of potatoes is so small that the quantity of seed used is barely recovered. It prominently attracted our attention in 1917, and it has been under examination ever since.

The disease attacks the plants in the following manner. At any stage of the plant's growth, but generally after it is a month old, spots with a very slight, somewhat oily-looking, blackish colour begin to appear on the underside of the leaves, and especially on the younger foliage. These spots turn reddish, extend in area and in number very rapidly, and ultimately become a bronze colour, giving an almost uniformly reddish tinge to the leaves. The upper foliage of the plant acquires a bunched-up appearance, the edge of the leaves becomes wrinkled and the leaf hairs become very prominent. Gradually, commencing from the top, the whole of the foliage withers leaving however the main stalk still green and living, though it also ultimately becomes discoloured and withers (Plate VI, figures 1 and 2). The plant endeavours to recover, by giving out a series of auxiliary shoots, which are, however, rapidly attacked and wither accordingly. All these stages only require from thirteen to fifteen days from the beginning to the final ruin of the plants. The attack usually occurs after the tubers are formed and when they are about the size of a walnut. They cease, however, to develop further and hence the yield consists of a very small weight of very small potatoes.

At first a few single plants are attacked, but from these the disease spreads in patches until the whole fields are affected. This spread is very rapid. As an example a

1. Typical Attack of Tambera Disease.

PLATE VI.

PLATE VII.

(*To face page 78.*)

1. **Plants inoculated with Tambera mite.**

PLATE VII.

2. **(1) Plant inoculated with Tambera.**

patch of potatoes which was carefully watched in 1919 may be described. The whole patch of potatoes was thirty-three feet square. On the first day only four plants could be detected with the disease, three near one corner and another nearer the centre of the field. Five days later the whole of the corner of the field round the former plants and a large circular patch round the latter were obviously attacked. Three days after, the whole field was affected except a narrow strip down the middle, while on the thirteenth day from the commencement of the field was red and withering from end to end. The disease comes on almost as if a fire is passing through the fields and is universally attributed by the cultivators to the prevalence of light, misty rain which often occurs during the months of August and September.

It is obvious that a disease like this is of very great importance, and it indeed appears to be the factor which limits the spread of the cultivation of potatoes during the *kharif* season in Western India. It has now been found not to be limited to the Poona potato area, but also occurs in other districts and even in Sind. It has been noticed in the *rabi* (winter) crop also, but there it never does any serious harm and it may be almost ignored unless this crop is very late.

All attempts to trace the immediate cause of the disease for a long time proved futile. Fungus diseases were absent, and no trace of a bacterial affection could be found. Everything indicated that the attack was due to a parasitic attack of some sort, but it was not until 1919 that the nature of the parasite was discovered. At that time our attention was drawn to a disease which appeared to be of a very similar kind reported from Hawaii in 1917* and which was attributed to the work of a mite. The appearance shown in the illustrations of the disease seems to agree very closely with

* Carpenter, C. W.—"A new disease of the Irish Potato". Phyto-Pathology, Vol. VIII, page 286 (1918).

that shown in *tambera* and hence a careful search was at once made for the very minute mites described. We had already been able to produce the disease at will by growing the potato plants under conditions of high temperature, and on examination they were found to be swarming with mites exactly similar in character to those found in Hawaii.

These mites are found on all the affected parts, especially on the under-surface of the leaves of the plants. They are so small as to escape notice with the naked eye, until the eye is trained how to look for them, and even with a hand lens unless carefully looked into. They can, however, be easily seen in all stages under the microscope with a low power. The eggs are peculiar sculptured bodies rounded oval in shape, and firmly attached to the leaf. The egg cases, even after the emergence of the larvæ, persist for long time as colourless, transparent objects, still retaining the sculpturing in the form of rows of small opaque white globules. The young mites are hyaline, have three pairs of legs and are sluggish. They moult, and the skins thrown off by them are seen in great numbers as white specks. The adult female is a clear amber colour, with smooth glistening skin, and has a fourth pair of legs which are much thinner than the remaining ones. It is an oval active creature moving about on six legs while the other two are dragged behind, and measures one-fifth by one-tenth millimeter. The male is of the same colour with a brownish tinge but is quite different in size and shape. It is more orbicular and smaller, measuring one-tenth by one-eleventh millimeter, with a clouded dorsal spot, and it possesses strongly developed legs and is much more active than the female. The first pair of legs has two joints, the second and third pairs have five joints and the fourth pair has four joints and each joint bears a few hairs.

The mites apparently suck up the juice from the epidermal cells of the leaves with the result that the leaves

are unable to stand the heavy drain on them and wither prematurely. The mites then leave such leaves and go in search of fresh leaves which they easily reach by crawling over from plant to plant as the plants touch one another. Whether they are, like some other mites, carried by insects or other agencies is not known.

The naming of the mites is the work of a specialist. Carpenter does not attempt it. He makes a formal statement that they may belong to the same group as the so-called red-spider (*Tetranychidæ*).

The mere presence of the mite is not, of course, sufficient to enable us to attribute *tambera* disease to it unless the connection is proved by actual inoculation experiments. Carpenter in his paper does not record any experimental evidence, but bases his conclusions on the mere presence of the mites. He states as follows:—"That these minute organisms are responsible for the disease seems evident. They are present in sufficient numbers on the plants with the recognised symptoms to warrant this conclusion and the reaction of the plant is such as we have come to associate with mite injury. Furthermore, if the mites be kept off a portion of the plants by spraying or dusting with sulphur those so protected develop normally while adjacent unprotected plants are devasted."

The following inoculation experiments were, however, carried out. At first only two plants in pots were brought into the laboratory and on being convinced that they were quite free from the mite attack one was used for inoculation and the other as control. Inoculation was made by putting, on the plant to be inoculated, affected shoots from a diseased plant containing mites. The inoculated plant began to show the symptoms on the third day. On the fifth day these were quite clear and on the eighth day the withering of leaves commenced (Plate VII, figure 1). The control plant kept away from the inoculated one did not show

any of the symptoms and remained quite healthy (Plate VII, figure 2). Encouraged with this trial, experiments were made on a greater number of plants. Ten plants were raised in pots. Five were used for inoculation and five for control. Inoculation of the plant was done as before (on the 5th of August 1919) by placing on them the affected shoots containing mites. The plants began to show the disease on the next day, and on the fourth day the symptoms were quite evident, namely the bunching of shoots and the browning of the under-surface of tender leaves. At this stage the examination of a browned leaf under the microscope showed any number of moving mites with their eggs. On the eighth day the shoots were completely bunched up and were much darkened in colour. In one plant leaves were withering. Thirteen days later, most of the top leaves of all plants were quite reduced in size and dried up. The controls remained quite healthy during this period. The results of the experiments conducted, in the same way, in the fields, too, were quite conclusive. Leaves affected with mites were attached to a few plants in a corner of a plot where there was no disease and the plants were kept under observation. The inoculated plants alone took the disease and the attack started from the point of contact with the affected leaves. The mites were again found in intimate association with the disease on the new plants.

The causal connection of the mites with the disease at once suggested a method of control by spraying with a sulphur wash, or by dusting with sulphur, and preliminary trials were made in pots where the potatoes were seriously affected. Both methods proved effective, and it was found possible to revive plants which were in a very advanced stage of the disease. Experiments on small plots proved equally effective.

The potato crop is so valuable that the application of such a spraying method as a safeguard against the disease

would pay well, and hence a limited area in the fields of the cultivators has been sprayed with lime sulphur wash, or dusted with sulphur, during the season of 1919, three dressing being given commencing from the time when the plants were three weeks old. The results were excellent and a demand at once rose from the people to spray their whole area. The season and the disease had, however, by that time advanced so far that it was impossible to do anything in that year. Spraying with lime sulphur wash, however, was a little more effective than dusting with sulphur. Three treatments were given—the first when the plants were three weeks old, the second when about six weeks and the third when they were between two and three months from planting. The difference between the yield of the sprayed fields and those unsprayed in the immediate neighbourhood in 1919 was very great. The yield of the unsprayed plot was only 1,000 lbs. per acre, or practically the amount of seed used : that of a plot sprayed after the attack commenced was 5,000 lbs. per acre; that of a plot sprayed from the beginning was 8,720 lbs. per acre. The cost of the complete spraying treatment was Rs. 13 per acre, but this can be materially reduced. At present spraying, though more effective, is a new process to the cultivators and it is probable that dusting with sulphur from muslin bags will be more generally used.

An attempt has been made to see if any of the varieties available are immune to the disease. All those commonly cultivated are, however, rapidly attacked if conditions are favourable. An English variety "Epicure," in experimental trials seemed to possess some resisting power, but further experiments are necessary with it. The favourite variety in Poona, a round, white, Italian type, known in Western India as "Talegaon," was the first to be attacked, and the other local varieties soon followed.

It is difficult to say how the mites which cause the disease are carried over from year to year. Looking to the

field conditions of the tract where these observations hav been made, it appears that the disease may possibly b carried over on the potato plant itself. Although there are two definite seasonal crops, the *kharif* and the *rabi* with regular intervals, the seasons are not sharply defined and potato cultivation goes on practically uninterruptedly between June and March. The *kharif* crop is sown in June and July and is harvested in September and October sometimes even in November. The sowing of the *rabi* crop begins in November and extends even up to the end of January, the harvesting of very late planted crops not being completed till the end of June. Stray plants arising from the remnant tubers of the previous crop are also found in the fields. It is thus seen that the potato plants are found throughout the year in the tract either as a regular crop or as stray plants, and the *rabi* crop though not seriously attacked is not by any means free from the mite. Owing to the cold weather the disease never does much damage and hence does not attract attention. The mite, however, comes into activity again as soon as the hot weather sets in in March and April. From the hot weather crop it is probably carried to the *kharif* season again.

Another possibility, of course, is that the mite may have other host plants. So far we have found what appears to be the same mite on *guvar* (*Cyamopsis psoralioides*) only. On this plant it has been recorded from Baroda, Padra, Surat and Poona. Cross-inoculations have proved that the *guvar* mite and the potato mite are one and the same. Potato plants when infected with the *guvar* mite easily took the disease. Chilli and tomato plants were also tried, but they remained free from the disease. More observations and experiments are required on this point.

B.—The Stem Borer of Potatoes.

There is a commonly occurring pest of potato in the whole of the Khed tract to which little attention has been

hitherto given, but which is well known to the people, as it occurs regularly and does damage, though not very serious damage, in both the *kharif* and *rabi* seasons.

The affection occurs in almost any stage of the plants' growth, when the top of the plant suddenly falls over and withers without affecting, however, the remainder. It never spreads lower in the plant. The people term this *mathemaru* (that is to say 'the pest that kills the top') and on close examination a hole is found in the stem just at the bottom of the withered portion. The caterpillar, by which the damage is caused, pupates in the stem just below the hole to which we have just referred, and the pupating stage lasts from eight to ten days. In potatoes at Saugor (Central Provinces) a few pupae were found in the eye of the tuber, but this was no evidence of their doing damage to the potato.

The moth which then emerges has been identified as *Leucinodes orbonalis*, a not unfrequent pest of brinjal (egg plant), but one which has only been recorded once or twice from potato. In this part of India, on the other hand, we have never seen it attacking brinjals, though on potato it is quite common. The eggs are usually laid on the underside of the midrib of the top leaves of the plant, generally one or two at one place and never in larger groups. Hatching of the eggs takes place after about nine days, but we have not been able to rear the caterpillar beyond this stage in confinement. On the plant in the field, however, we have been able to watch the life history and have found that the caterpillar requires fifteen to twenty days for its life, while the pupal stage lasts for six to eight days.

The caterpillar enters the stem at once, on hatching, and never does any damage to the leaves or to the outside of the shoot. The place of entering the stem is very small, and can only be seen with difficulty. The caterpillar is hairless and very sluggish (unlike that of the potato tuber moth which is active) and when mature is about one inch

in length. The moths are never observed flying and mating in the potato fields.

No experiments have been made to deal with this pest, but it often damages a very large number of plants as in 1917 and 1918. No evidence is in hand as to how far it affects the weight of the crop.

IX.—THE STORAGE OF POTATOES

By H. H. Mann, D.Sc. and S. D. Nagpurkar, B.Ag.

A.—Black Heart or Heat Rot of Potatoes in Storage.

In all work done on potatoes in India which involved storage there has been constant trouble because the potatoes when kept through the hot weather tended to show an enormous and unexpected amount of rotting. When such rotting potatoes were examined they showed in many cases a *fusarium* fungus, in many others a *rhizoctonia* fungus, and in others various kinds of what appeared to be forms of bacterial rot. And as a result it has been customary to attribute the hot weather rotting of potatoes in store to one or other of these causes. But the rotting often comes on so suddenly when the temperature rises and involves so completely almost the whole of a bag or a consignment of potatoes that it is difficult to believe that any or even all of the above causes were the main source of the rot which was liable to cause such tremendous destruction and loss.

It is extraordinary that attention has not been more closely directed to the subject until recently. Perhaps the real reason has been simply that potatoes are much more a temperate than a tropical crop, and the difficulties of storage have usually been rather those resulting from too low than from too high a temperature. All specifications as to the storage of potatoes* are so worded as to avoid the possibility of frost, and though the advisability

* See, for instance, Bulletin No. 724, United States, Department of Agriculture.

of preventing rise of temperature is insisted on, there is rarely if ever any indication that the temperature may be so high as to cause at least equal damage to that produced by freezing.

In India potatoes have, however, to be kept, at least for seed, over the hot weather, and the difficulties have been recognised by the people, and arrangements made to minimise the evil as far as possible. The description of the open air method of storage carried out by the cultivators in the Khed taluka will be found in Chapter V (page 33), but though the combination of shade, moisture, and aeration which their method secured gave them some security, yet every year when the temperature was high, the loss was enormous, and on opening the stores the potatoes were often covered with masses of fungus of various kinds and to these fungi the rotting has been usually attributed.

Attention was, however, called to the fact, by Bartholomew* in 1913, that a type of rotting, which he termed 'black heart' of potato is caused by rise of temperature alone especially if air is excluded and since that time the matter has been investigated by several people. The most recent account of it, with a very large number of experiments on the subject was published by Stewart and Mix in 1917.† The present knowledge of this rotting of the potato tubers due to heat together with lack of aeration is summarised by these last two workers as follows:—

"Present knowledge of black heart in potatoes rests upon investigations made by Bartholomew who proved that it may result from exposure of the tubers to a temperature of 38-45° C. for 14-48 hours and is due to changes in the tissues caused by a derangement of the process of respiration.

"The accidental discovery that by excluding the air from potatoes black heart may be produced at temperatures

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* Phytopathology Vol. III, page 180 (1913).

† New York Agricultural Experiment Station, Bulletin No. 436 (1917).

much lower than those employed by Bartholomew led the writers to make experiments with tubers in sealed jars.

"From such experiments it was learned that potatoes cannot long endure close confinement. Within a certain length of time, which varies with the temperature and quantity of air available, tubers confined in hermetically sealed jars become moist over a part or whole of their surface. If the tubers are then exposed to the air the moist surface areas turn brown and the colour of the flesh changes first from white to pink to black (black heart).

"With a volume of air equal to the volume of the tubers a confinement of ten or twelve days is sufficient to produce the symptoms described provided the temperature is around 70°F. At a temperature of 55-60°F. about twenty days are required; and at 40°F. a still longer time somewhere between twenty-three and forty days.

"Tubers in half-full and quarter-full jars behave similarly to those in full jars except that the symptoms are slower in making their appearance.

"Different tubers of the same lot exhibit marked differences in susceptibility, both to black heart and to surface discoloration. The cause of this has not been determined. It appears doubtful if the size of the tubers is an important factor.

"The injury resulting from insufficient aeration is due to the lack of oxygen rather than to the accumulation of carbon dioxide.

"Tubers affected with black heart produced by exposure to high temperature usually appear normal externally, while those affected with black heart produced by exclusion of the air usually show more or less surface discoloration.

"Tubers severely affected with black heart are unfit for seed purposes, but slightly affected tubers may be planted. If tubers are sound and normal in appearance it is unlikely

PLATE VIII.

Potato attacked with Heat-Rot.

that they have been injured for seed purposes by any storage conditions to which they may have been subjected."

Our attention was forcibly drawn to this type of rotting during the hot months of 1918, when we had a very valuable lot of pedigree potato seed which had to be carried through the hot weather. This was stored in bags in a well aerated and lofty room, facing north. The shade temperature outside, however went up over 100°F. and within a few days a large part of the stock became rotten and useless. This caused a much closer investigation into the subject, and the result has been to confirm in every particular the results just quoted, and to lead to methods which have enabled us to carry potatoes over the hot weather either in Poona or in the potato district itself. These methods will be described in the next section.

While we were doubtful as to the cause of the rotting which gave us so much trouble, we made experiments to see whether we had to deal with a parasite. As a matter of fact, *rhizoctonia* fungus (*rhizoctonia destruens or rhizoctonia solani*) is so universally prevalent among our potatoes that it is rarely that this fungus cannot be obtained by cultivation from them,* and it was at first thought that the rotting was due to this fungus. But the rotting produced by this fungus is essentially near the surface of the potato at any rate in the early stages, while the 'heat rot' is very deep-seated and in fact appears generally to start from the heart. The *rhizoctonia* rot is, moreover, very much blacker in colour, and on the whole, the two can be very easily distinguished.

No other parasite is usually present, and the 'black heart' is 'heat rot' is in no way infectious. Good potatoes can be treated with the rotting material in any way without any effect being produced. The tubers can be buried in soil mixed with the rotting potatoes, they can be cut

* The cultivations made from these potatoes were all very kindly carried out for us by Mr. G. S. Kulkarni, B.Ag.

with a knife just used to cut a rotting tuber, or they can be watered with the watery oozings from an affected potato, without effect, provided the temperature be not allowed to rise or aeration to be restricted.

As already indicated by the above quoted authorities, the heat rot when highly developed causes loss of germinating power, and the potatoes cannot be used for seed. This has been found on a large scale in 1920 where the people of Khed and one or two other villages bought Italian seed with the object of planting it near the end of February. It was attacked with the rotting, and was then planted, almost entirely in vain, only a few plants growing out of the crop. But if the attack has only just started, and there is little or no sign on the outside of the tuber that the black heart is present in the tuber, the potatoes will grow healthily, and give good healthy plants. At present it is impossible to say exactly at what stage the tubers lose their power of germination.*

Enough has been said with regard to the 'heat rot' or 'black heart' of potato to show how vital a factor it is in the potato problem in Western India. If we can eliminate this kind of rotting, then the other fungus rots of storage (except perhaps *fusarium* rot) will not, we feel, be really serious obstacles to progress. But this heat rot makes the keeping of large quantities of seed a very difficult problem, and so far as potatoes for food are concerned makes a regular market a very difficult thing to maintain, fluctuations of price being extraordinarily great. What we have been able to find out and apply in actually storing potatoes will be discussed in the next section.

B.—Methods of Storage of Potatoes through the Hot Weather.

The shade temperature conditions in the Deccan, that is to say in the Poona and Khed area, during the time when

* The results of a chemical study of the effect of black heart on the potato is given in he Appendix.

potatoes have to remain in storage between February and June are shown in the following figures for Poona. Those from Khed will be very similar, while the higher plateau at Peth and surroundings village will be a little cooler :—

Temperature.	February.	March.	April.	May.	June.
Mean maximum ..	91·3°F.	99·1°F.	101·7°F.	100·1°F.	91·9°F.
Mean minimum ..	57·2°F.	63·1°F.	68·6°F.	71·6°F.	72·6°F.
Absolute maximum in 5 Years).	99·5°F.	105°F.	108·1°F.	107·6°F.	105°F.
Absolute minimum in 5 Years).	42°F.	48·5°F.	50·5°F.	65·6°F.	67·4°F.

Now our experiments have indicated that, apart from actual diseases present in the tubers, there is no danger in storing potatoes at any temperature below 86°F. and little danger below 90°F. provided that there is sufficient aeration among the stored tubers. The above table will show that the period of danger, therefore, when there will be some difficulty in keeping the temperature down to this point, will really start in March and continue until the latter part of May, and this is actually found to be the case in practice. It is during this period from early March to the end of May or later if the monsoon rains are delayed that the difficulty of storage occurs.

To get over this period without ruining their seed potatoes the cultivators use the method of field storage which has been already described (page 33) but which essentially consists in digging a shallow pit under the shade of a tree or under a roof, filling this with water and allowing the latter to soak away. The potatoes are then spread in it eighteen inches deep and covered with grass and broad leaves. The temperature is kept down by occasionally filling a ditch dug round the pit with water, and splashing the heap of potatoes with water. In such heaps we found the temperature rose to 92°F. to 93°F., but so far as our tests went, not higher than this. If the shade is considerable the temperature does not rise so high, and one store at Chakan

which only reached 86°F. was noticed. Thus in such heaps the temperature keeps fairly well within a safe limit, and if the potato moth was not a serious trouble, there would be little need of any better system.

Many other cultivators store in substantially built store houses in the village. Here the potatoes are usually kept in heaps from two to three feet thick, and in the case of seed potatoes, they are turned over and sorted frequently. The temperature in these heaps at the latter part of May was between 86°F. and 88°F. and occasionally it rose to 93°F. This was the highest temperature that we found Again the method seems fairly satisfactory in the absence of potato moth, but with the latter in the houses (as is often the case) the system breaks down and there is a very large loss. In fact if potato moth cannot be elimianted there is no practicable method of storing except in bags. We would say, however, that when the process of fumigation of potatoes becomes general, it will probably be possible to revert to these two methods, as the amount of potato moth will be reduced within very small limits. At present this is not the case, and storage in bags is essential, in order to protect the fumigated seed from reinfection by moth.

Before going on to consider the methods which we have used to make storage in bags reasonably safe, let us consider some examples of the actual losses in storage which now occur by the ordinary cultivators' methods as described.

Field Storage.—

(1) *Village Khed.*—Stored from March 24th to June 6th. Quantity stored—20 tons.

	Per cent.
Loss due to moth attack ..	10
Loss due to dry rot ..	4
Loss due to miscellaneous wet rots	13
Total loss ..	27

(2) *Village Peth.*—Stored from April 2nd to June 4th. Quantity stored—15 tons.

	Per cent.
Loss due to moth attack ..	30
Loss due to dry rot and miscellaneous wet rots	6
Total loss ..	36

House Storage.—

(1) *Village Khed.*—Stored from March 24th to June 1st. Quantity stored—5 tons.

	Per cent.
Loss due to moth attack ..	12
Loss due to dry rot and miscellaneous wet rots ..	7
Total loss ..	19

(2) *Village Chakan.*—Stored from April 13th to June 3rd. Quantity stored—6 tons.

	Per cent.
Loss due to moth attack ..	5
Loss due to dry rot and miscellaneous wet rots ..	3
Total loss ..	8

(3) *Village Awasari.*—Stored from April 6th to June 5th. Quantity stored—40 tons. Temperature did not exceed 88°F.

	Per cent.
Loss due to moth attack ..	32
Loss due to dry rot ..	5
Loss due to miscellaneous wet rots	33
Total loss ..	70

These cases are not typical, but represent the results obtained by careful men in the Khed potato area. The loss in the last quoted case is not unknown even among the best men if the seed used in the field for growing has been unsatisfactory.

Now from what has been indicated previously (page 37) the loss from moth attack can be eliminated, or practically so, by fumigation. This should be done a few days after the potatoes are lifted, as described previously. For the purpose of fumigation they are contained in bags, and after fumigation the next necessity is that before being put into storage in these bags the potatoes should be removed and carefully sorted. When this sorting is done they can be stored with safety in bags in the houses which the cultivators usually use for this purpose. Examples of such storage are as follows:—

A. Village Peth.—Stored from April 2nd to June 4th. Quantity stored—35 tons. Fumigated, sorted and bagged and stored in the usual house.

		Per cent.
Loss due to moth attack	..	*Nil*
Loss due to miscellaneous rots	..	9·4

B. Village Shiroli.—Stored from March 30th to June 6th. Quantity stored—6 tons. Fumigated, sorted and bagged and stored in house.

		Per cent.
Loss due to moth attack	..	*Nil*
Loss due to miscellaneous rots	..	2·3

C. Village Khed.—Stored from March 24th to June 6th. Quantity stored—1½ tons. Treated as in the last case.

		Per cent.
Loss due to moth attack ..	..	*Nil.*
Loss due to dry rot ..	..	1·7

The secret of success in the above cases was the sorting of the potatoes from every form of rot before final bagging after fumigation. Fumigation alone will not do; it gets rid of moth but other rots tend to increase rapidly in the stored potatoes. But if to fumigation is added careful sorting of the fumigated potatoes before storage and keeping of the potatoes below a temperature of 90°F. in a well-aerated house, there ought to be little further difficulty.

In order to get these results, however, the following precautions must be taken :—

(1) Each bag must stand separate from all others, having free air all round it.

(2) The bag must be completely filled tight, so that the folding of the bag will not prevent aeration.

(3) The bags must not be piled upon one another.

(4) The bags must be stood upright.

In our experience if any of these points are neglected there is a tendency for the temperature in the bag to rise, and cause loss through heat rot.

As an example of what can be done by these methods with a fair average lot of good seed, we will indicate the system adopted during the last famine in 1919 to preserve the local stock of seed potatoes which had almost disappeared on account of the drought conditions. Part of the stock, amounting to 70,800 pounds, were preserved at Peth without any special arrangements not obtainable in a village—while parts were preserved in Poona in a specially constructed storage house.

The stock at Peth was by no means a satisfactory one, as has already been stated. We purchased what was available from cultivators of good repute, after a preliminary sorting from obviously diseased or very inferior seed at the time of purchase. This eliminated 33 per cent. of the stock

offered to us for sale.* The remainder had to be stored from April to the latter end of June. During this time we lost potatoes as follows :—

(1) Lost owing to ring disease .. 407 lbs. or 0·57 per cent.
(2) Lost owing to dry rot .. 1,117 lbs. or 1·58 per cent.
(3) Lost owing to miscellaneous wet rots .. .. .. 1,683 lbs. or 2·37 per cent.
(4) Lost owing to heat rot .. 178 lbs. or 0·25 per cent.

The total loss was therefore 4·77 per cent. exclusive of driage.

To obtain this result the bags of potatoes were fumigated with petrol vapour immediately on receipt in order to get rid of moth which was present though not a very serious extent. One fumigation was not found entirely sufficient, so after a sorting for ring disease, a second fumigation was undertaken. The actual storage was made in stone walled houses in Peth village. The temperature outside went above 101°F. and in an ordinary open shed with stone walls to 95°F. In our stores we were able to keep it down to 91°F. without special cooling arrangements,—but we finally adopted a system of hanging canvas sheets round the sides of the stores wherever air could enter, and keeping

* It is interesting to note the reasons for this elimination of potatoes offered for sale. They were as follows :—

Total amount of potatoes offered	.. 108,000 lbs.
Rejected—	
(1) On account of ring disease	.. 6,300 lbs.
(2) On account of dry rot	.. 14,100 lbs.
(3) On account of miscellaneous rots	.. 2,700 lbs.
(4) On account of very small size of potatoes ..	.. 12,900 lbs.
Total rejections	.. 36,000 lbs.
	(33 per cent.)

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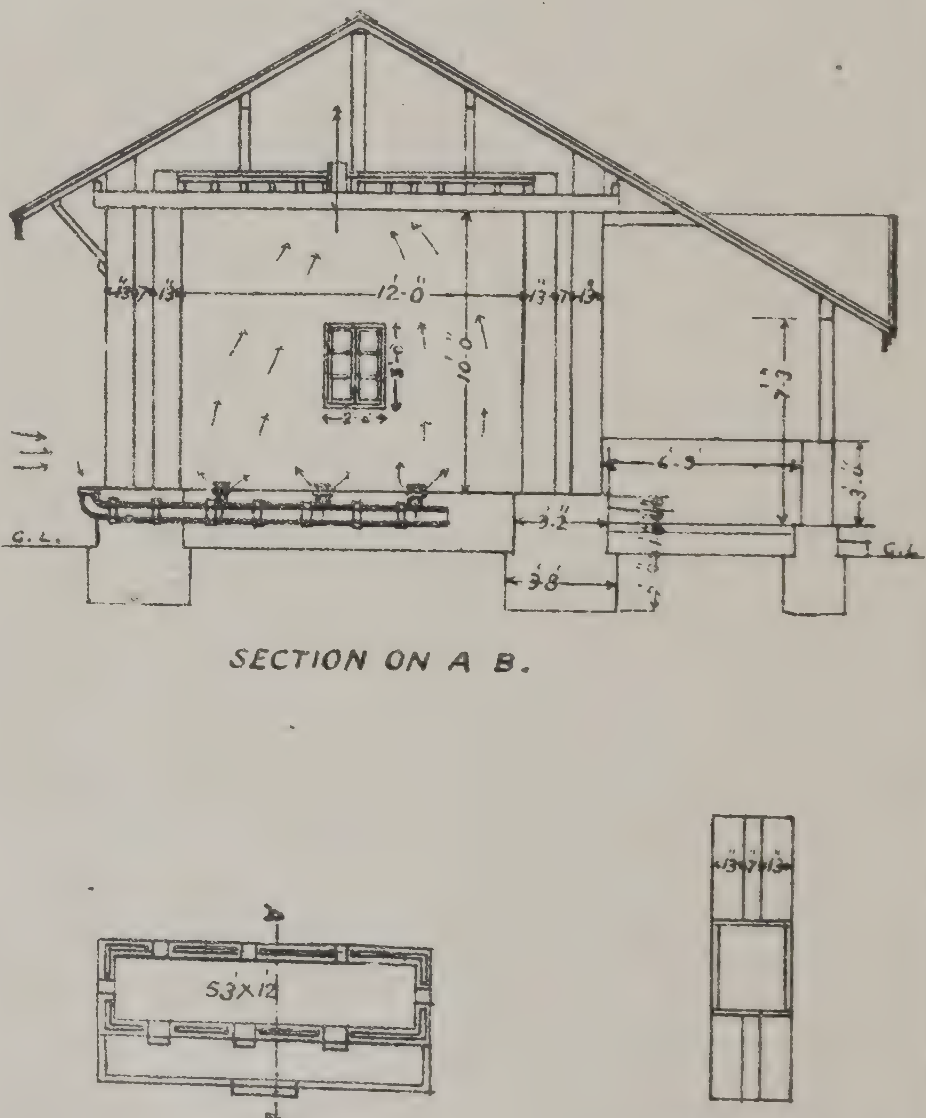
POTATO STORAGE HOUSE



SECTION ON A B.

PLAN

SECTION THROUGH WINDOW

these wet. After the adoption of this method, the temperature did not rise above 85°F. and heat rot, which was just starting, was checked. On the other hand, the attack of *fusarium* (dry rot) went on increasing, and we made the greater part of the loss on this account in the last three weeks of storage. All storage was in bags, with repeated sorting.

During this storage the following points were noticed :—

(1) Potatoes harvested a little before the plants became completely ripe and yellow, kept better than the others, especially so far as dry rot (*fusarium*) was concerned.

(2) Potatoes which had been treated carelessly by the cultivators in that they had been exposed to hot winds showed almost immediate signs of heat rot in the tubers. Once heat rot showed itself in a tuber nothing could save it from complete rotting.

(3) We formed the conclusion, which needs confirmation by further experiment, that the potato moth caterpillar is an important means of spreading various rots in the store, especially dry rot and some of the forms of wet rot.

(4) Potatoes affected with ring disease do not usually rot in storage, unless the attack is already in an advanced stage.

The conditions in Poona were more trying for here the temperature was higher, the maximum reaching 103°F. during the storage months. But here we had the advantage of a specially built storage house, placed at our disposal by Messrs. The Union Agency of Bombay, which is, we believe, the first of its kind in Western India. The place was designed to protect against moth infection from outside, and also against high temperature and the resulting heat rot.

The plan of the building is as follows :—As the essential point was to keep the building cool, well aerated and

inaccessible to potato moth, it was made on all sides with double walls with an air space between them, and on the south a verandah six feet wide. The store room itself was thirteen feet wide and the windows and doors could not only be closed during the hotter part of the day, but also, when open, were covered with wire gauze, permanent in the case of the windows, and forming an inner door in the case of the doors. The roof was of tiles, but underneath this was a ceiling covered with earth to a depth of four inches. The ceiling was open all round the edge and was pierced by several openings in the centre. There was a chimney in the roof through which, in the hot weather, there was a continual draught.

During the hotter part of the day both doors and windows were closed, and at this time aeration was obtained through holes in the floor, which were connected with the outside air by means of drain pipes partially filled with water. The whole arrangement is shown in the section of the building illustrated in the accompanying plan. Skeleton shelves can be built in the store room which will allow two layers of bags of potatoes to be stored without in any way interfering with the aeration of either layer.

The store room so built has been a distinct success in Poona, and though somewhat expensive in first cost, it prevents a great deal of rotting. The windows are kept open from 8 p.m. to 6 a.m. in the hot weather, and are then closed. The temperature has been kept as low as 82°F. when the outside shade temperature has been rising as high as 101°F.

We have, therefore, reached a system by which potatoes kept for seed can be maintained without anything like the serious losses which have often, if not usually, been incurred in the past. It is based on fumigation in the first instance, followed by rigid selection of diseased potatoes, and then storage in bags kept separate from one another in a godown so arranged that the temperature shall not rise above 90°F

Unless these conditions can be secured, potato storage in the hot weather in the Poona district seems impossible without very large loss.

In detail, the method is as follows :—

(1) Within a week or ten days of harvesting the stock of potatoes contained in bags should be fumigated with petrol vapour as described in the chapter on the potato moth. This can be now done easily as fumigation chambers are established in a number of the villages of the Khed potato tract, and fumigation carts can be taken to other centres.

(2) After fumigation the potatoes should undergo a rigid selection for ring disease, *fusarium* (dry rot), and any miscellaneous wet rots which are contained in the stock. Most of the rejected potatoes can be sold at once for food purposes.

(3) The potatoes should then be rebagged, and stored in a stone-walled godown or in one specially made (as described above). The bags must stand separately, must be full, and they must not be piled on top of one another. The godown must have a free through draught of air, and (in the absence of special arrangements to achieve the same object) the open doors should be hung with curtains of canvas kept wetted during the hotter parts of the day.

(4) After each month in store the bags should be opened and rotten potatoes should be removed.

X.—THE MANURING OF POTATOES IN WESTERN INDIA.*

By H. H. Mann, D.Sc., S. R. Paranjpye, M.Ag., and S. D. Nagpurkar, B. Ag.

Potatoes are recognised throughout the area now under consideration as an intense crop which will pay for a good

* Most of the information in this Chapter will be found in Bulletins Nos. 76 and 89 of the Bombay Department of Agriculture by H. H. Mann and S. R. Paranjpye.

deal of expenditure in the way of manure, and it is therefore usual for the people in almost every tract to utilise a considerable portion of the limited amount of manure available on the potato crop. Artificial manures have, except in experiments originated by ourselves, practically not been employed. In spite of the utilisation of whatever farmyard manure is available, the lack of sufficient of this to give all that the plant needs is one of the causes of the low yield obtained, and if the losses caused by the low quality of seed used, and the field diseases to which we have referred can be minimised, it will pay to manure much more heavily than at present and to use artificial manures.

The best cultivators in the Khed tract give up to about 12 cart-loads (10,000 lbs.) of farmyard manure to the acre, and in addition they often fold sheep on the land which it is intended to put under potato. The following are examples of the actual manuring given in certain cases by some of the best known cultivators in the tract.

A. One cultivator of Peth on the *kharif* crop of 1917, put on 12 cart-loads (10,000 lbs.) per acre of farmyard manure, mixed this thoroughly with the soil, and then folded 500 sheep per acre for four days on the land. From land so prepared he obtained a crop of 11,845 lbs. per acre, weighed eight days after harvest.

B. Another cultivator of Peth, on the *rabi* crop of 1917-18, put on 12 cart-loads (10,000 lbs.) per acre of farmyard manure only, and mixed this thoroughly in the soil. From this he obtained a crop of 6,460 lbs. per acre, weighed eight days after harvest.

C. A cultivator of Awasari, on the *rabi* crop of 1917-18, put on 16 cart-loads (13,000 lbs.) per acre of farmyard manure, and mixed this thoroughly with the soil in the usual manner. He obtained 10,080 lbs. per acre, weighed some days after lifting. This area is renowned for high yields.

D. At Manchar, on the *rabi* crop of 1917-18, 12 cart-loads (10,000 lbs.) of farmyard manure per acre were used. The crop was 9,642 lbs. weighed as in the previous cases.

These may be considered as the maximum yields obtained in ordinary cultivation. It is recognised that much higher crops can be obtained, particularly in the *rabi* season, and on the offer of a prize for the maximum crop obtainable, a cultivator at Manchar used 24 cart-loads (20,000 lbs.) of farmyard manure per acre and obtained 15,700 lbs. per acre of crop, weighed as before. This may represent the highest yield ever obtained in the district.

The average yields are far lower and the quantity obtained in the Khed tract does not certainly average more than 5,500 lbs. per acre in the *kharif* season, and 6,600 to 7,700 lbs. per acre in the *rabi* season. It is probably lower than this.

Our experiments have chiefly dealt with the employment of artificial manures, and have been carried on since 1913-14. The standard system of manuring adopted was to put on the usual dressing of farmyard manure (10,000 to 12,000 lbs. per acre) and *in addition* a mixture of sulphate of potash (180 lbs. per acre), sulphate of ammonia (120 lbs. per acre) and superphosphate (280 lbs. per acre). The average results of experiments made with this manure in the *rabi* season of 1913-14 were as follows, the artificial manures being applied just before planting :—

	Lbs. per acre.
Farmyard manure alone	9,146
Farmyard + complete manure as above	14,912
Farmyard + superphosphate and sulphate of ammonia only	12,627

With these results the use of the artificial manures in addition to the local manure could be fully justified.

Experiments in later years have amply confirmed these results and have in addition shown that the amount of sulphate of potash can be reduced without very great loss of yield. In a series of experiments on this point the following results were obtained in the *rabi* season :—

	Lbs. per acre.
Farmyard manure alone	8,425
Farmyard + complete manure with 150 lbs. sulphate of potash per acre ..	14,010
Farmyard + complete manure with 112 lbs. sulphate of potash per acre ..	13,450

The reduction of the potash manure has evidently, in the last case, gone too far, with a corresponding diminution in yield.

Our experiments, further, have shown that as a source of readily available nitrogen, sulphate of ammonia is superior to nitrate of soda if the quantities used contain the same quantity of nitrogen. The formula used was :—

	Lbs. per acre.
Sulphate of potash	150
Superphosphate	112
Sulphate of Ammonia	120
or	
Nitrate of soda	170

A series of experiments with these mixtures gave results as follows in the *rabi* season :—

	Lbs. per acre.
Farmyard manure alone	9,875
Farmyard + artificial manure with sulphate of ammonia	15,699
Farmyard + artificial manure with nitrate of soda	13,866

We can, therefore, state clearly that the following mixture of artificial manures represents the best and most

paying dressing for potatoes that we know as yet in the Khed area when used in addition to the usual dressing of farmyard manure under the conditions already indicated :—

			Lbs. per acre.
Sulphate of potash	..	..	150
Superphosphate	..	..	112
Sulphate of ammonia	..	..	120

Of course, if a reduction in price of nitrate of soda occurred, it might become more profitable, but there is no doubt that the nitrogen in sulphate of ammonia is actually more efficient with this crop.

With the use of this mixture it has been possible to get high yields, at the same time reducing the quantity of farmyard manure. In a prize competition among the cultivators of the Khed area, the following results were obtained :—

Manure.	Lbs. per acre.	Yield of potatoes. Lbs. per acre.
1. Farmyard manure ..	20,000	15,700
2. Farmyard manure ..	13,000	..
and 200 lbs. of the above-mentioned mixture of artificial manures per acre	..	15,324

In this case the possibility of replacing farmyard manure in the *rabi* season is clearly shown.

We have not done any satisfactory experiments on manuring in the *kharif* season and such experiments are useless until *tambera* disease is brought under control.

XI.—THE VARIETIES OF POTATOES GROWN IN WESTERN INDIA.

By Harold H. Mann, D.Sc. and S. D. Nagpurkar, B.Ag.

We do not know when potato cultivation was introduced into Western India, and where the seed used was obtained

from. Though there are earlier references to the matter, the earliest clear and definite record of the cultivation in the Khed area was near Junnar in 1841. Later on, when any attention was paid to the potato cultivation it was found that the whole district was growing a round, white, smooth-skinned potato whose eyes were of medium depth. This had a somewhat thin skin, and white eyes. The eyes averaged ten per tuber. The flesh was yellowish-white, not granular. The stem of the plant was purple at the base. This variety was found, in the year 1884 and following seasons, according to the account given by the people, to be very susceptible to the disease which we now know as *tambera*. Then the ring disease came in, from what source we do not know, and this variety proved very susceptible and potato cultivation in the early nineties was in very serious danger of extinction. Under these circumstances, Italian white round potatoes, imported here for food, were tried for seed and did very well. This variety gradually replaced the older one, and very nearly all of what is now grown is of this type, though a few of the older variety are often found mixed with it. The Italian variety is itself not pure and contains, even as imported, an admixture of long red and oval red types also. Up to 1900 the Italian variety was not really popular, as the older type of potato previously grown was reputed to keep better and not to be so susceptible to rot. The famine of 1900, however, as far as we can tell, destroyed the stock (as has again happened in 1918-19). The Italian seed was the only suitable and available seed to replace it, and was found, moreover, to yield better. Hence it has now all but completely driven out the older type.

The Italian white round variety which is now almost exclusively cultivated in the Poona and Khed area has the following characteristics. It is round, rather flat at the ends and with somewhat of a bulge in the middle. The skin is rough and thick, and the colour whitish brown. The number

of eyes is from ten to fourteen. The eyes are deep and white in colour. The flesh is white gradually becoming yellowish on exposure and granular. The stem of the plant is pale-green throughout. When grown here the tubers are not large, though as imported they are of good size. Their principal advantage is that (1) they are capable of giving a good outturn on black soil in both the *kharif* and *rabi* seasons, (2) though susceptible to *tambera* disease, they are less so than nearly all other varieties tried, (3) they will grow under conditions of greater heat than most exotic varieties which have been tried here, (4) the amount of rot (largely dry rot) in storage is less than with other varieties grown in India, (5) the arrangement of the eyes on the tuber is such that many sets can be made from one tuber, (6) on cutting the flesh the tuber remains yellow, forms a corky layer and does not rot.

This same variety is the principal one in cultivation at Belgaum, and Dharwar, Satara, Bangalore, Karachi and the Central Provinces. In Karachi and Bangalore, however, and in Ahmedabad a kidney potato is also grown which is the principal variety in North India and the lower Himalayas. This latter is also grown under the name of '*malti*' at Mahableshwar, and its characteristics are as follows. It is a long flat potato reddish-white in colour, with a thin and smooth skin and scarlet eyes. The eyes are very shallow, and are clustered at the growing end of the potato. The flesh is yellowish and waxy. The stem of the plant is green. This variety grows well in the early *rabi* season at Karachi and Ahmedabad, but will not stand hot weather anywhere, and even in the above centres the Poona (Italian) variety is chosen for the hotter parts of the year.

A few further notes may be given with regard to the other varieties grown at Mahableshwar.

1. *Mumbasa kidney.*—This kidney potato tapers very markedly at both ends and is very flat. The colour of the

skin is yellowish-white, and it is thick and rough. The eyes are shallow and the flesh is milk-white and granular. The stem of the plant is pale-green.

2. *Gulabi.*—This is a long, flat, kidney potato, with brown skin having a red tinge. The skin is smooth and thin, and eyes are somewhat shallow. The eyes are red, and the flesh of the tuber is white with a reddish tinge. The stem of the plant is pale-yellowish.

3. *Tambada.*—This variety probably also originally comes from Italy and is a round oval potato of a red colour. The skin is thin and smooth. The eyes are shallow and deep red in colour. The flesh is whitish yellow and granular. The stem is pale-green.

We have no record of the behaviour of these last three under cultivation in the hotter conditions of the Deccan.

Many efforts have been made to introduce the best English and other varieties of temperate climates in our potato areas. These have invariably failed, as when any crop at all was obtained, the yield was always much less than that got from the varieties already under cultivation. The record of the latest attempts to utilise some of these varieties, under our own control, may be told.

Seed tubers of the following well known varieties were imported in 1918 from England :—" Epicure," " Great Scot," " Ever Good, " " Iron Duke," " Irish Queen, " " Queen Mary," " Arran Chief," " British Queen." The results obtained from each of these in the Khed and Poona area was as follows in two seasons :—

	Planted in October. Yield per acre. lbs.	*Planted in January.* Yield per acre. lbs.
Local white round seed ..	9,427	6,800
Epicure	1,920	1,600
Great Scot	680	280

	Planted in October. Yield per acre. lbs.	Planted in January. Yield per acre. lbs.
Ever Good	520	80
Iron Duke	1,600	360
Irish Queen	480	880
Queen Mary	920	440
Arran Chief	70	*Nil.*
British Queen	2,800	560

These were also grown at Peth in the *kharif* season, but no crop was obtained, chiefly as a result of a bad attack of *tambera* disease.

Altogether we may note that all the varieties named suffer badly as soon as the weather becomes even slightly hot. Then they are attacked seriously with *tambera* disease, and in a few days the plots are completely scorched and withered. It is, obvious, in fact, that any variety to be successful here must have characteristics which have been very little considered in working out the very choice varieties in Britain. These characteristics are (1) a capacity to stand high temperature both when growing and in the store, (2) a thick skin so that dry rot and other rots may not attack the tubers as a result of infection in store, (3) if possible, a capacity to resist *tambera* disease, at least to a limited extent, (4) a general distribution of the eyes so as to allow economy of seed, (5) a capacity to yield well even under conditions of fairly high temperature and irregularity of water supply, (6) a power to grow in both the *rabi* season under irrigation and in the *kharif* season with rain.

XII.—GENERAL CONCLUSIONS.

By Harold H. Mann, D.Sc.

The survey which we have now made of the conditions of potato cultivation and its difficulties in some of the more important tracts in Western India will not be complete

unless we try to piece together the results, and give an idea of the needs of this industry and of its prospects for the future. As we write, in 1920, the potato-growing industry has almost disappeared for the time being in the Khed and several other areas, as a result of the demands of Mesopotamia in 1917-18 which denuded the country of any surplus stocks, of the famine of 1918-19 which very largely destroyed the crops in the *kharif* season of 1918 and prevented the planting of the *rabi* crop in 1918-19: and of the impossibility of importing fresh supplies of seed from Italy in 1919 until almost too late for *rabi* planting in most centres and absolutely too late in many.

The immediate effect of the famine in 1918 can be illustrated by one or two figures. In the Khed tract the potato crop was reduced in the *rabi* season of 1918-19 from a normal area of about four thousand acres to only about three hundred and thirty. On the Peth plateau, where there is a group of potato-growing villages, the area under this crop went down from a normal of 716 acres to only 25 acres in the *rabi* season of 1918-19, and to 20 acres in January 1919-20 (*rabi*). At present the revival of the industry depends, as it has done after every famine since that of 1900, on the import of Italian seed. Neither the seed of north or of south India is suited for the black soil areas, and it is very difficult to get Italian seed at any rate when it is wanted, and it can only be stored with very great difficulty. The times when seed is particularly wanted are June when it is in demand for the *kharif* crop, and in October to December for the *rabi* crop. In 1919-20, to relieve the famine for potato seed, permission was obtained for the import of a certain amount of potato seed from Italy too late for the regular *rabi* season. It arrived at the beginning of January. Some parts of the Khed tract refused to have anything to do with it knowing that the planting was too late and it would be a failure. Others planted the seed.

In suitable villages those who planted by the third week in January got an excellent crop, but the character of the return from seed planted after that date rapidly got poorer and poorer as the date of planting got later, and seed planted on February 10th, even under the best conditions, returned only twice the amount of seed tubers used. We would definitely say now that for the Deccan tract any attempt to plant later than February 1st is most risky and foolish. Hence the result of the lateness of the arrival of this seed this year has been that much of it has never been planted, and as it was *rutu* and hence useless for food, and would not keep till the *kharif* season it has been lost. As a result it will be rather difficult to restock the district, by private enterprise, and in the near future.

But it is only a matter of time before the areas will be restocked with seed, and as the crop is one which yields a very large profit, it is important that its future history should not be so dominated by troubles and difficulties, as has been the case in the past. It was a recognition of the existence of the numerous difficulties that led to the investigations whose results up to date have been recorded in these pages. The report of Mr. Keatinge in 1909, quoted on page 33, gave some idea of the parlous condition of the industry, and close touch with the Khed district in connection with manurial experiments from 1913 onwards led to the taking up of the present study. As a result the chief obstacles in the way of development have become fairly clear, and we have, we think, been able to show how to meet them in part, while much more investigation will be required to enable the others to be conquered.

In the first place, we may say that it has become clear that the maintenance and keeping of good seed is the primary matter to which attention must be directed. The destruction of seed in store by the potato moth is the primary

difficulty. To this the cultivators have always asked us to devote the first attention, and they are right. The very simple method of fumigating the reaped potatoes in bags with petrol vapour and subsequent storage also in bags under specified conditions enables this difficulty to be met. We have established permanent fumigating chambers in five of the principal villages of the Khed potato tract (under the control of village potato associations, of which more later) and have also provided, under the control of the agricultural department, two travelling fumigators which can be taken from village to village. The extension of this system of fumigation of potatoes, at any rate if to be used for seed, is only a matter of time, provided we can get rid of the very large loss which has been usually incurred by storage in bags. It is obvious that this method of storage is necessary, if reinfection with potato moth is to be avoided.

We have succeeded in determining the conditions of such storage without large loss from rotting, and it only remains to bring the methods which have been worked out in general use. They are simple and can be applied in every village in the Khed tract. Essentially these conditions are three, as follows :—

(1) The rigorous sorting of the potatoes after fumigation, and the removal for immediate sale, of every potato which can be detected as suffering from ring disease, from dry rot however small the patch may be; or from any form of soft or wet rots. This sorting is troublesome, but there will be a market for most of the removed potatoes, if sold immediately; while they will be worthless, beside infecting others, if kept with the remainder of the lot.

(2) The careful storage of the good potatoes in bags which are stored in a well ærated godown with the bags (*a*) full up to the top, (*b*) standing singly, (*c*) standing upright, and (*d*) not piled one upon another. Aeration is necessary or rotting will be very great.

(3) The keeping of the temperature in the godown and among the stored potatoes below 90°F. so as to avoid heat rot. To achieve this, the store must be substantially built and roofed. This is not usually a difficulty in the Deccan, and in case the temperature tends to rise above the figure quoted it is necessary to hang canvas screens on the doors on the windward side of the godowns, and keep these wet during the hotter parts of the day. We had no difficulty in keeping the temperature to 85° to 86°F. in Peth by this method.

If these methods are adopted we think there will be little further difficulty in preventing the stored potatoes from rotting, and the seed will improve by the gradual elimination of the *fusarium*-attacked potatoes. It may be necessary to resort the potatoes every month during the storage.

But all this will only provide good seed if ring disease be absent or almost absent in the tubers. We have shown that the seed is the sole important source of the perpetuation of ring disease, and it cannot be eliminated anything like completely by sorting. Its presence, however, in seed means the inevitable death of plants, and before the famine it prevailed to the extent of forty to fifty per cent. in much of the seed in use. To get rid of it, however, means continual renewal of seed from Italy or the establishment of pedigree seed, selected and grown here from generation to generation until free from the disease. The former is the simplest if the price of the seed is of no importance and if there is security that we shall always be able to get the seed that we want when we need it. If these conditions are not fulfilled it is necessary to adopt the second alternative and establish pedigree seed here practically free from ring disease. A step has been taken in this direction, and it would appear to be a legitimate sphere of operation of the agricultural department to maintain this seed in limited quantity, transferring

it for further multiplication to a commercial agency or to a quasi-commercial agency such as a co-operative society formed for the purpose.

The next necessity is the development and application of the methods for dealing with *tambera* disease. The recognition of this as the principal cause of small yields in the *kharif* season, and the most serious field enemy of the crop is quite recent. Nobody fancied two years ago that it did the damage it is now proved to produce. But the use of dusting or spraying methods, with sulphur or sulphur preparations, would seem to remove it from the category of real dangers, and so far as appears at present it would henceforth be a conquered foe, if only the necessary amount of trouble is taken.

If the programme so far outlined is carried out the principal difficulties in the way of the industry will be removed. There is much still to do. The study of the fusarium rot of stored potatoes has been hardly begun. The methods of dealing with the very destructive *rhizoctonia* wilt disease—which we believe will be chiefly by improvements in cultural methods—have hardly been investigated at all. The necessity of continual testing and even breeding of varieties in order to get a type which suits the conditions here better than anything we have at present is obvious. And the increase in the normal yield from the present very low standard by means of manuring is another method whose development is essential. These are the immediately necessary lines of progress, both in investigation and propaganda.

For propaganda work and the helping of the cultivators we have developed an organisation in five of the chief villages of the Khed tract which has worked well until the recent collapse of the industry and is still there. In each of these villages there has been established a 'potato association' composed of twenty of the leading potato cultivators. This

association is in charge of the fumigating chamber in the village and arranges how it shall be used by its members and by others. So far a fee has not been charged for this use, but that will be the next development. Then a young intelligent local cultivator's son has been selected and trained by us in each case to fumigate, to select seed potatoes, to store by the best methods, to detect the various kinds of diseases in the field, and as far as possible to deal with them. This man is placed under the charge of the potato association and is at the service of the members and of others with the members' consent.

The whole organisation has been supervised by one of those responsible for the work, who frequently toured in the district and kept closely in touch with the potato associations and their members, their men, and their difficulties. Such is the way in which the work has been carried on and its development is only a matter of time.

In conclusion we may say that the investigations and work which have formed the subject of the present bulletin have been rendered possible by special financial assistance from two or three sources. Messrs. The Union Agency of Bombay have assisted perhaps most largely in placing at our disposal one, and at times two graduate assistants, paying their salaries and all their expenses from the early part of 1917 to 1920. In addition to this, a special grant of Rs. 10,000 from the profits of the wheat operations in 1917, was made towards the cost of the work by the Government of India in 1918, and its continuation is now assured from a grant recently made by the trustees of the Sir Sassoon David trust for agricultural inquiries. We can only hope that the further progress achieved will lead to the solution of the remaining problems of potato culture, at least on the Deccan.

APPENDIX.

A CHEMICAL STUDY OF "HEAT ROT" OR "BLACK HEART" OF POTATO.

By H. H. Mann, D.Sc. and B. M. Joshi, B.Sc.

I.—Introduction.

One of the difficulties constantly met with in tropical countries in connection with the cultivation and the keeping of potatoes is the fact that when the tubers are stored, at any rate in the hot weather, there is a very large amount of rotting among them. In the past this has been usually attributed to the presence of fungi and bacteria, and to a very large extent they are the cause of the loss incurred on this account. We have found fungi present on the surface of the potato always, and often beneath the skin (having entered probably through the lenticels) so that even after careful disinfection of the surface, fungal growth is still obtained. And, moreover, the conditions of storage at high temperatures are very favourable to the growth of such fungi and bacteria as may be present. But the wholesale rotting of whole consignments of carefully sorted potatoes, when the temperature rises, has often led to the suspicion that the fungi and bacteria usually found were not the primary cause of the decay.

Two special instances caused us to give close attention to the matter. In the first place, we had produced, prior to 1918, a somewhat valuable lot of pedigree seed potatoes, free from ring disease of the Italian variety usually grown in the Deccan, and during the war it was impossible to replace this supply from Italy or any other source. They were, however, stored during the hot weather of 1918, in bags, in a lofty and well-ærated room, facing north, in Poona. The temperature outside however rose to over 100°F., and within a few days a large part of the stock became

rotten and useless. When the potatoes which were still good were sorted out, and kept under very carefully cooled conditions at not over 85°F. no further rotting occurred. In the second place one of us organised the despatch of large quantities of seed potatoes to Mesopotamia in 1917 and 1918, and whatever care was taken in selection and packing, the report was always made during a large part of the year that before use a large quantity had decayed with a soft wet rot.

It was obvious, therefore, that we had to deal not with an ordinary parasitic attack, whether by fungi or bacteria but with some thing which was intimately connected with rise of temperature. And at this stage our attention was called to work done and observations made by Bartholomew * in 1913 and by Stewart and Mix † in 1917 in which descriptions are given of very similar rot produced, generally during shipment, in America. This rot was attributed by both the authorities quoted to rise of temperature, especially when the rise of temperature was accompanied by lack of æration.

The general character of the change now under consideration is very obvious to the naked eye. While, in the presence of adequate aeration, healthy potatoes at a temperature of 27° to 30°C. do not appear to undergo any microscopic changes except a slow driage, when that temperature is exceeded, there occurs a darkening of the tissues, starting from the centre of the tuber with certain varieties but by no means with all. The original description given by Bartholomew in 1913 is absolutely accurate so far as some of our potatoes are concerned, but we would specially draw attention to the great differences that exist between the reaction of different varieties to the temperature factor

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* E. T. Bartholomew—Black Heart of Potatoes—Phytopathology, Vol. III, page 180.

† F. C. Stewart and A. J. Mix—Black Heart and the Aeration of Potatoes in Storage, New York Agriculture, Expt. Stn. Bulletin, No. 436 (1917).

and hence to the production of heat rot. As found in the Italian white round potatoes with which we have worked, the course of the attack is usually as follows :—

The flesh of the potato, generally on one side, but sometimes in the centre takes in a pinkish tinge. This spreads over nearly all the tuber before any further appearance is noted. Then at any part of the tuber, but often near the centre, a small patch of dull dark colour appears, soft to the touch and in which, obviously, degeneration of the contents of the cells is taking place. At a temperature of 36°C. the changes to this part usually take about six days. Most of the potatoes at this stage have become soft, but one or two in every set of twelve remained hard, or rather increased in hardness. After this stage is reached further degeneration is rapid, and by the twelfth day the whole potato is greyish black in colour, very soft and pulpy often with watery matter oozing out, and it smells badly. No bacteria are present when precautions are taken, though it is often difficult if not impossible to eliminate *Rhizoctonia* fungus (*Rhizoctonia solani*) which often grows, in spite of all surface sterilisation in the tuber just under the skin.

The degeneration of the potato tuber which we have described is so marked, so rapid, and so complete that it was quickly felt to be interesting and possibly important to ascertain, if possible, the chemical changes which accompany it, particularly in the initial stages, in order that it might be detected and checked before it does any serious harm to a store of potatoes. We are not sure whether the results which we can now present will enable us to do what we hoped, but the experiments are sufficiently interesting to be worthy of record.

The design of our experiments was to compare the composition of similar potatoes which were kept, on the one hand under conditions of temperature and aeration where no obvious degeneration took place, and on the other,

where conditions of aeration being practically the same, the temperature was raised to a point where rapid roting set in. The first experiments were undertaken to ascertain the temperatures which could be used for the purpose. The potatoes were enclosed in wire cages and placed in incubators at various temperatures. It was found that at 27° to 30°C. there was no danger of rotting under these conditions and that the potatoes remained good, without any signs of the darkening of the tissues which is characteristic of the degeneration for much more than the twelve days during which each experiment as a rule lasted. At 36°C. changes, however, took place under otherwise similar conditions and the potatoes became soft and the tissues darkened about six days after the potatoes were placed in the incubator. At this temperature the changes we were studying are slow and regular, and it was adopted as the standard for the study we were making. At 41° to 42°C. the degeneration was very rapid. Within two days the tissues were darkened, and in six days the tubers were completely soft and rotten.

In all these experiments small potatoes of even size were used and of course of the same variety,—the Italian white round potato grown in the Deccan. Each potato used weighed between 30 and 35 grammes. Tubers, kept as described, were taken for analysis at intervals of two or three days. Twelve potatoes formed each sample. Half of each of these were pounded to a pulp, and immediately examined. In most of the experiments, as already stated, the potatoes were in wire cages. In much of the later work, when we were testing the effect of various gases, the tubers had to be kept in sealed glass cylinders.

II.—Methods of Analysis Used.

The following determinations were made during the course of the work, and the methods used are indicated.

1. *Moisture.*—The moisture was determined by drying thin slices of the potatoes in the steam oven.

2. *Total Soluble Matter.*—The potatoes were pulped, a weighed portion of the pulp mixed with water, allowed to stand, filtered and the clear filtrate evaporated.

3. *Total Nitrogen* was determined by the ordinary Kjeldahl method, using potassium sulphate only (not mercury).

4. *Ammoniacal Nitrogen.*—This was obtained by distillation with magnesia, and titration of the distillate received in standard acid, with standard alkali.

5. *Insoluble Proteid Nitrogen* was obtained by washing the pulp first with cold and then with hot water, and then using the ordinary Kjeldahl method with the residue.

6. *Total Proteid Nitrogen.*—This was determined by mixing the pulp with water, and adding Stutzer's reagent (cupric hydroxide suspended in water). After standing in a steam bath for half an hour, the whole was filtered, the residue washed with hot water and then the nitrogen determined in it by the Kjeldahl method.

7. *Amido Nitrogen* was obtained as the difference between the total nitrogen and the other fractions determined. Thus Amido-nitrogen = Total nitrogen—(total proteid nitrogen + ammoniacal nitrogen).

8. *Soluble Proteid Nitrogen* was obtained by difference between the total proteid nitrogen and the insoluble proteid nitrogen.

9. *Reducing Sugar.*—The potatoes were pulped, 50 grammes were then taken and mixed with cold water, and allowed to stand for one hour. The whole was then filtered through linen cloth, and washed with warm and finally with cold water. The filtrate was treated with basic lead acetate and made up to 500 cc. After filtering, precipitating with sodium phosphate, filtering and concentrating, the reducing sugar was determined with Fehling solution in the usual fashion.

10. *Total Sugar.*—The original solution obtained in the last named determination, after filtering off the starch very carefully, was inverted with hydrochloric acid, and in the resulting liquid the total sugar determined with Fehling solution as usual.

11. *Gummy Matter and Dextrin.*—Twenty grammes of the pulp was extracted with 96 per cent. alcohol for three hours and filtered ; 100 cc. cold water were added to the residue and the whole kept for 20 hours. Upon filtering a clear solution was obtained which gave no starch reaction with iodine. This solution was slowly concentrated to a small volume, avoiding a temperature higher than 80° to 90°C. and was then treated with several volumes of strong alcohol until no further precipitate was produced. The flocculent precipitate was filtered off and weighed giving the percentage of gummy matter and dextrin.

12. *Alkalinity and Acidity.*—Ten grammes of the pulp were taken mixed with cold water and kept for two hours. The liquid was then filtered, carefully washed, and titrated (1) with standard caustic potash using phenol phthalein as indicator to determine the acidity, (2) with standard sulphuric acid, using methyl orange as indicator, to determine the alkalinity.

13. *Catalase.*—Two grammes of the potato pulp was taken, and a large excess of neutral hydrogen peroxide solution was added. The flask was kept continually shaken for four hours, the temperature being maintained constant in a water bath. The gas evolved was collected and measured throughout the operation.

14. *Oxidases.*—The method devised by Bunzel * with minor modifications of technique was used. About 20 grammes of potato were taken, pulped and pressed through cloth. 2 cc. of the juice were used for the experiment and the actual tests were made at a temperature of 36°C. each being continued for four hours.

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* United States, Department of Agriculture, Bureau of Plant Industry, Bulletin 238 (1913).

III.—Chemical Changes accompanying Heat-Rot in Air.

1. *Moisture.*—Potatoes kept in an incubator whether at 27°-30°C. or at 36°C. generally lost a little water, but as the atmosphere was always nearly saturated the drying did not usually go very far, and a loss of water or a change in water content did not seem to be in any way specially associated with the phenomena described. Two illustrations of this may be given—

A.—Potatoes exposed at 27°-30°C. and at 36°C. without any preparation or treatment :—

	Water determination in		
	(1) Fresh Potatoes.	(2) Potatoes at 27°-30°C.	(3) Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.
Fresh Potatoes	72·7	..	..
After 3 days exposure	..	72·2	71·2
After 6 days exposure	..	72·1	71·1
After 9 days exposure	..	71·0	70·8
After 12 days exposure	..	70·3	70·2

B.—Potatoes exposed at 27°-30°C. and at 36°C. having been previously dipped in copper sulphate solution to check surface fungi :—

	Water determination in		
	(1) Fresh Potatoes.	(2) Potatoes at 27°-30°C.	(3) Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.
Fresh Potatoes	75·4	..	..
After 3 days exposure	..	73·1	71·9
After 6 days exposure	..	73·5	75·9
After 9 days exposure	..	73·7	75·9
After 12 days exposure	..	74·0	75·1

In the first of these experiments the loss in the proportion of moisture in the tubers was practically the same in the two cases and amounted to 3·4 per cent. In the second case the loss was much smaller and was less at the higher temperature than at the lower.

The actual total loss in weight of the tubers is not very different from the loss in moisture recorded in the first case quoted above. The total loss in weight, in one case, was as follows :—

Loss of weight at 30°C.			Per cent.
(1) in 3 days	..	..	1·1
(2) in 6 days	..	..	2·0
(3) in 9 days	..	..	2·2
(4) in 12 days	..	..	2·7

Though respiration is taking place, as we shall see later, the greater part of the loss during the experiments is apparently due to driage.

2. *Total Soluble Matter**.—The following figures show the amount of total matter soluble in water at different stages. The present experiment was made with the potatoes in glass cylinders and was allowed to continue for twenty-two days, or long after the potatoes kept at the higher temperature were rotten, and when those at 27°-30°C. were also in a rotting condition :—

			Total Soluble Matter.	
			Potatoes kept at 27°-30°C.	Potatoes kept at 36°C.
			Per cent.	Per cent.
Fresh potatoes	..	..	16·4	16·4
After 2 days	..	..	16·4	16·8
After 4 days	..	..	16·4	17·2
After 6 days	..	..	16·8	17·6
After 8 days	..	..	17·6	17·2
After 10 days	..	..	17·2	16·8

* The results throughout have been calculated on the basis of the dry matter contained in the potatoes. W here this could not be determined it has been assumed as 75 per cent.

	Total Soluble Matter. Potatoes kept at 27°-30°C.	Potatoes kept at 36°C.
	Per cent.	Per cent.
After 12 days	17·2	17·6
After 14 days	18·0	17·6
After 16 days	17·6	20·0
After 18 days	18·0	20·8
After 20 days	17·6	20·4
After 22 days	18·0	20·4

In both cases there is a small and very gradual increase in the amount of soluble matter in the potato. The rate of increase during the first twelve days does not however differ in the potatoes kept at the different temperatures. The sudden rise after 14 days at 36°C. is obviously due to other causes and probably to the presence bacterial rots when the degeneration of the tuber has gone so far.

3. *Acidity and Alkalinity.*—The tubers used in the last determination were employed for the estimation of the acidity, and alkalinity. It might have been expected that the rotting described would be characterised by a substantial change in these characters. If the rotting were essentially a fermentation of the carbohydrates, then the acidity would be expected to increase. If on the other hand, it was a decomposition of proteids, the alkalinity might have been expected to become greater. Neither of these changes takes place. There appears to be an immediate rise in the acidity of the potato at the higher temperature, but thereafter it remains constant until the rotting is fully established (12 days) and only rises after that time when bacterial rots supervene. Likewise the alkalinity, though slightly higher at the higher temperature, remains constant until the rotting is fully established. All figures are calculated on dry matter and the figures represent

the equivalent of H_2SO_4 or sulphuric acid or potassium hydroxide respectively in one hundred grammes of dry matter.

	Acidity.		Alkalinity.	
	Potatoes at 27°-30°C.	Potatoes at 36 C.	Potatoes at 27°-30 C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh Potatoes ..	0·96	0·96	1·92	1·92
After 2 days ..	0·96	1·32	1·92	2·32
After 4 days ..	0·96	1·16	2·20	2·20
After 6 days ..	0·96	1·16	1·92	2·20
After 8 days ..	1·16	1·16	2·20	2·20
After 10 days ..	0·96	1·16	1·92	2·32
After 12 days ..	0·96	1·16	1·92	2·20
After 14 days ..	0·96	1·16	1·92	2·32
After 16 days ..	0·96	1·36	1·92	2·48
After 18 days ..	0·96	1·56	1·92	2·48
After 20 days ..	0·96	1·44	1·92	2·40
After 22 days ..	1·16	1·48	2·20	2·40

4. *Forms of Nitrogen.*—As we had no wish to follow the changes subsequent to the complete establishment of the heat-rot, the investigation of the alterations in the various forms of nitrogen present in the tubers was not continued beyond the twelfth day, the tuber being kept

in open wire cages. The results were however as follows, all figures being based on the dry matter present in the tubers :—

	Total Nitrogen.		Ammoniacal Nitrogen.		Amido Nitrogen.		Total Proteid Nitrogen.		Insoluble Proteid Nitrogen.		Soluble Proteid Nitrogen.	
	27°30' C.	36° C.	27°30' C.	36° C.	27°30' C.	36° C.	27°30' C.	36° C.	27°30' C.	36° C.	27°30' C.	36° C.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Fresh Potatoes .	1·47	1·47	0·016	0·016	0·55	0·55	0·88	0·88	0·44	0·44	0·44	0·44
After 3 days ..	1·4	1·4	0·014	0·014	0·68	0·66	0·72	0·71	0·47	0·44	0·25	0·27
After 6 days ..	1·4	1·4	0·030	0·049	0·64	0·70	0·78	0·77	0·49	0·49	0·29	0·28
After 9 days ..	1·4	1·4	0·035	0·051	0·65	0·67	0·71	0·74	0·48	0·48	0·23	0·26
After 12 days..	1·4	1·3	0·048	0·088	0·68	0·66	0·71	0·75	0·46	0·47	0·25	0·28

The total nitrogen, therefore, obviously does not alter and the insoluble proteids are not dissolved during the process under discussion. There is furthermore no marked change either in the amido nitrogen or in the soluble proteids. On the other hand the ammoniacal nitrogen has increased very largely and while the increase is present even in the absence of the rotting, it is much more rapid at the higher temperature. The rapid increase coincides with the beginning of the degenerative changes between the third and the sixth day, and at the twelfth day the quantity of ammoniacal nitrogen is nearly double what it is at the lower temperature.

5. *Forms of Sugar.*—No investigation of the individual sugars was made, and we simply determined the total sugar and the portion of this which was capable of reducing

Fehling solution. The results were as follows, the tubers being kept in open wire cages :—

	Total Sugar calculated (as glucose).		Reducing Sugar (as glucose).	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh Potatoes	3·0	3·0	0·3	0·3
After 3 days	3·1	4·1	0·30	0·33
After 6 days	3·9	5·9	0·29	0·31
After 9 days	3·2	4·4	0·32	0·34
After 12 days	2·3	3·7	0·40	0·47

These results are of considerable interest. The total sugars immediately increase at the temperatures we are using and very much faster at the higher temperature. Then when the rotting becomes established there is a rapid reduction in the quantity present. The highest point reached at 36°C. corresponds with the commencement of the obvious rotting of the tuber. So far as the reducing sugars are concerned there seems a slow but steady increase during the exposure of the tubers, and this is more rapid at the higher temperature. The connection with the rotting is not however very obvious.

6. *Gummy Matter and Dextrin.*—The variation in the gummy materials which we have classed together under this head is very interesting and it seems more closely connected with the heat-rot than any constituent so far examined. The figures are as follows :—

	Dextrin.	
	Per cent.	Per cent.
Fresh Potatoes	1·1	1·1
After 3 days	0·93	0·84
After 6 days	0·93	1·3
After 9 days	1·1	2·4
After 12 days	1·3	3·5

After a preliminary fall in the amount of gummy matter at the beginning of storage, the increase in these constituents at the higher temperature is constant and substantial, while at the temperature below the rotting stage it is very small indeed. In the potatoes attacked with heat-rot the increase after six days is 18 per cent. after nine days it is 118 per cent. and after twelve days it is 218 per cent. while in those below the rotting temperature it never reaches more than 21 per cent.

From the preliminary results so far recorded, therefore, it is clear that among the constituents examined, the heat-rot is characterised by a marked increase in the ammoniacal nitrogen, by the increase in the total sugar, which afterwards declines, by a steady increase in the amount of reducing sugar to a greater extent than in potatoes kept below the rotting point, and by very large increase in the amount of those gummy substances which we have classed together.

These results were preliminary, however, as no special precautions were taken to exclude the action of surface fungi. The constituents just named were now determined in potatoes similarly kept, but which were first dipped in two per cent. copper sulphate solution, allowed to dry and then exposed to the temperatures required in open wire cages. The results under these conditions are shown by the following figures :—

1. *Total Nitrogen and Ammoniacal Nitrogen.*

	Total Nitrogen.		Ammoniacal Nitrogen.	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh Potatoes	1·7	1·7	0·04	0·04
After 3 days	1·6	1·5	0·045	0·045
After 6 days	1·6	1·7	0·045	0·057
After 9 days	1·6	1·7	0·046	0·08
After 12 days	1·5	1·9	0·050	0·10

These figures confirm in a striking manner the results previously given. The total nitrogen does not alter, but the ammoniacal nitrogen rapidly increases at the rotting temperature while there is little rise at 27°-30°C. The proportion of rise at 36°C. is shown by the following figures :—

			Per cent.
(1) 3 days	..	..	12·5
(2) 6 ,,	..	..	42·5
(3) 9 ,,	..	..	100·0
(4) 12 ,,	..	..	150·0

2. *Forms of Sugar.*

	Total Sugar.		Reducing Sugar.	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent	Per cent.
Fresh Potatoes.	2·8	2·8	0·20	0·20
After 3 days ..	2·7	2·9	0·20	0·38
After 6 days ..	2·7	4·0	0·22	0·56
After 9 days ..	2·8	4·1	0·22	0·64
After 12 days ..	2·8	4·1	0·25	0·72

The result here, where we have largely eliminated the possibility of surface fungal growth, is rather different from what we have seen before. Here there is a rapid rise in both the total sugar and in the reducing sugar, and in neither case does the amount again go down in the latter part of the experiment. The present figures probably represent more closely the real effect of the heat-rot, as the elimination of fungi has removed one of the chances of error. At the same time, it suggests itself as a possibility that the very slow increase of total sugar in the latter part of the test really

indicates that it is being formed and consumed at the same time, and that what we get is simply a figure which shows the excess of production over consumption or *vice versa.*

3. *Gummy Matter and Dextrin.*

	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.
Fresh Potatoes	1·60	1·60
After 3 days	1·66	1·75
After 6 days	1·80	2·40
After 9 days	1·90	2·90
After 12 days	1·90	3·30

The figures here give results of the same order as those previously obtained. In the potatoes attacked with heat-rot the increase in gummy matter after six days is 50 per cent., after nine days it is 81 per cent., and in twelve days it is 106 per cent., while in those kept below the rotting temperature it never reaches more than 19 per cent.

So much for the actual materials in the potato. But the enzymes present may also be increased or diminished and it is possibly in the increased activity of these that the cause of the rotting lies. We therefore have determined the amount of two of the enzymes known to occur in the potato tuber, namely (1) catalase and (2) the oxidases. The tests were made with tubers which were protected by dipping in copper sulphate solution, from surface fungus attack, and were contained in sealed cylinders so that rotting took place in both cases, though it was more at the higher temperature.

1. *Catalase.*—The figures quoted represent the actual amount of oxygen given off by 2 grammes of potato pulp when placed in contact with a large excess of neutral hydrogen peroxide solution. The figures are, hence, comparative only. The experiment was allowed to continue for twenty-two days, when the high temperature potatoes were

completely rotten, and had probably been invaded by bacterial rots. The figures illustrate this point.

		Catalase. Potatoes at 27°-30°C. cc. oxygen.	Catalase. Potatoes at 36°C. cc. oxygen.
Potatoes after	2 days	14·1	8·9
Do.	4 days	17·2	9·2
Do.	6 days	14·6	7·2
Do.	8 days	11·4	5·1
Do.	10 days	19·9	5·4
Do.	12 days	22·8	4·5
Do.	14 days	13·3	4·1
Do.	16 days	16·6	63·7
Do.	18 days	18·8	82·2
Do.	20 days	18·4	70·2
Do.	22 days	16·7	75·2

These figures show at 27° to 30°C. as great a constancy as can be expected in such a determination even after rotting has commenced. On the other hand at 36°C. they show (1) an immediate reduction in the amount of catalase as compared with the potatoes at the lower temperature, (2) a further gradual reduction until an exposure of fourteen days is reached, the amount going down until it is only about twenty-five per cent. of the average at the lower temperature, (3) a sudden and enormous increase after the fourteenth day till the end of the experiment. We are inclined to believe that this last rise has nothing directly to do with the 'heat-rot' process. The potato was soft and oozing before the fourteenth day, and we think (though we have no proof) that the later rise in amount of catalase is due to the entrance of bacteria. Apart from this the reduction in the amount of catalase at the higher temperature is very marked, and together with the increase in ammoniacal nitrogen, the rise in the sugar and in the gummy matter, forms the most striking chemical indication of the occurrence of the heat-rot in the potato tubers.

2. *Oxidase.*—The proportion of oxidase was measured by the amount of oxygen absorbed in four hours by pyrogallol solution mixed with 2 cc. of the potato juice. The figures in the following table therefore represent cubic centimeters of oxygen absorbed in four hours as a result of the activity of the oxidase on the quantity of potato juice mentioned :—

	Oxidase.	
	Potatoes at 27°-30°C.	Potatoes at 36°C.
	cc.	cc.
Fresh Potatoes	0·169	0·169
After 2 days	0·169	0·182
After 4 days	0·195	0·143
After 6 days	0·208	0·156
After 8 days	0·214	0·162
After 10 days	0·228	0·221
After 12 days	0·357	0·231

In both cases the exposure to the temperatures in question led to an increase in the amount of oxidase but the rise was considerably more rapid at 27° to 30°C. than at the higher temperature. where rotting was more rapid. It is evident that the measurement of this group of enzymes is not likely to be of use as an indicator of the progress of the development of 'heat-rot' in the tuber.

So far, therefore, as the heat-rotting of potato tubers in air is concerned, the following statement indicates how far each of the chemical changes which we have investigated appear to be associated with it :—

(1) the total soluble matter increases whenever the tubers are kept at a high temperature, but this increase does not appear to be a measure of the amount of rotting.

(2) the acidity is not affected by the rotting, while the alkalinity rises when the temperature is raised, but thereafter remains constant and is not affected by the degenerative changes going on.

(3) of the forms of nitrogen, only the ammoniacal nitrogen seems to be increased during the rotting process. This increases very rapidly, and the rise may amount to as much as 150 per cent. in twelve days.

(4) the sugars increase rapidly during the rotting of the tuber, but the total sugar seems to reach a maximum and there stop if it does not decline. The reducing sugars continue to rise at least until the heat-rot has penetrated the whole tuber.

(5) the gummy substances increase rapidly during the rotting process, the quantity reaching at least twice or three times the amount previously contained in the tuber. Where the temperature is not sufficiently high to induce rotting, very little increase in the quantity of these gummy matters occurs.

(6) the catalase is quickly reduced at the higher temperature when rapid rotting takes place and when the whole tuber has been invaded it only amounts to one quarter the quantity present in tubers kept at a lower temperature where rotting is relatively slow. When bacteria invade the rotting tissue, the catalase rapidly rises again.

(7) the oxidase group of enzymes rises in quantity when potatoes are exposed to a high temperature. It increases however more slowly when rapid rotting is taking place than if the temperature is only high enough to produce the degenerative changes very gradually.

IV.—Chemical Changes accompanying Heat Rot when air is excluded.

The next point of interest was to ascertain how far the more important of the changes already described are affected by the exclusion of air, or in fact by the prevention of any respiration of the tubers. This was secured in two

ways. Either the tubers were (after destroying fungi on the surface by dipping in a two per cent. solution of copper sulphate and allowing to dry) dipped in collodion, or else they were coated with melted paraffin wax at a temperature between 40° and 50°C. Both these methods seal the surface from any respiratory exchange, but the collodion injures the eye buds at once, while the paraffin wax does not directly do so. The latter method was, therefore, preferable for the present inquiry, but we will give the figures obtained in each case. The potatoes protected by collodion were exposed in wire cages, and will be dealt with first. In this case rotting took place within twelve days at both the experimental temperatures, though of course it was more rapid at the higher.

1. *Total Nitrogen and Ammoniacal Nitrogen.*

	Total Nitrogen.		*Ammoniacal Nitrogen.*	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh Potatoes ..	1·70	1·70	0·040	0·040
After 3 days ..	1·68	1·60	0·043	0·050
„ 6 „ ..	1·62	1·64	0·050	0·050
„ 9 „ ..	1·62	1·64	0·048	0·052
„ 12 „ ..	1·66	1·65	0·052	0·068

We have here, therefore, as would be expected, no increase or decrease in the total nitrogen, and the gain in ammoniacal nitrogen at the higher temperature is proportionately less than occurred in air. The actual increase was as follows, in twelve days.

Percentage increase at 27° to 30°C.	30 per cent
Percentage increase at 36°C	70 per cent.

2. *Forms of Sugar.*

	Total Sugars.		Reducing Sugars.	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	2·80	2·80	0·20	0·20
After 3 days	2·80	2·80	0·21	0·21
,, 6 ,, ...	2·88	3·20	0·20	0·31
,, 9 ,, ...	2·80	3·20	0·20	0·50
,, 12 ,, ...	2·80	3·40	0·22	0·57

We have here a result which almost seems to indicate that the formation of sugars is not an essential part of the heat-rot, which seems to be capable of taking place without any considerable increase in their amount. At the higher temperature sugars are certainly formed, but it is difficult to consider their increase as being directly connected which the rotting process. At the lower temperature rotting was taking place after the sixth day, but no increase in the sugars is recorded.

3. *Gummy Matter and Dextrin.*

	Gummy Matters.	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.
	Per cent.	Per cent.
Fresh potatoes	1·60	1·60
After 3 days	1·05	1·14
,, 6 ,, ...	2·00	2·70
,, 9 ,, ...	2·30	3·60
,, 12 ,, ...	3·00	3·10

This result must be interpreted in the light of the fact that when air is excluded as in the present case, the heat-rot takes place at a much lower temperature than in the case with air, and that after six days rotting is taking place at 27° to

30°C. as well as at 36°C. The association of the increase of gummy matters with the rotting seems clear and is very striking.

In our experiments in which air was excluded by means of paraffin wax, the potatoes were stored in sealed glass cylinders, and so the rotting was easily obtained at the lower temperature of experiment. The actual history of the potatoes at the two temperatures of exposure in this case may be indicated.

At 36°C. even on the first day some slight depressions on the surface were noticed, which had extended a day later. Some swelling of the paraffin layer were noticed as water tended to accumulate in drops below it. By the next day on cutting the potatoes the surface layer of the flesh appeared pink, starting apparently from the eyes. The same outside signs continued, and on the sixth day when the potatoes were cut the surface layer was reddish brown, and some of the eyes were black. A small cavity had formed at the centre of one potato. After this the colour of the skin became rapidly black, and on the ninth day, the flesh under the skin was greyish black, but darker at the stalk and at the eyes. The tubers were quite soft at the eyes. On the twelfth day practically the whole of the flesh was greyish or reddish black and the tuber was quite soft.

At 27°C. to 30°C. though slight depressions formed on the surface of the tubers no pinkish colour was observed on cutting on the third day. No swellings were observed in the paraffin. On the sixth day the flesh below the surface was pinkish in certain cases, but had already become greyish black at the eyes. This was not by any means general, and even by the twelfth day only some of the potatoes were slightly rotting, especially at the stem, where there was a tendency to become soft and greyish black.

The chemical examination of the tubers gave results as follows :—

1. *Forms of Nitrogen.*

	Total Nitrogen.		*Ammoniacal Nitrogen.*	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.	Potatoes at 27° to 30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	1·60	1·60	0·040	0·040
After 3 days ..	1·60	1·62	0·037	0·036
,, 6 ,, ..	1·70	1·70	0·040	0·047
,, 9 ,, ..	1·80	1·60	0·045	0·050
,, 12 ,, ..	1·70	1·68	0·045	0·053

The increase in ammoniacal nitrogen in the rotting potatoes is again much less than occurred in air. The actual increase in twelve days was as follows :—

		Per cent.
Percentage increase at	27° to 30°C. ..	12·5
Do. do. at	36°C. ..	32·5

2. *Forms of Sugar.*

	Total Sugars.		*Reducing Sugars.*	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	2·10	2·10	0·24	0·24
After 3 days ..	2·32	2·40	0·24	0·24
,, 6 ,, ..	2·68	2·66	0·30	0·34
,, 9 ,, ..	2·40	2·41	0·37	0·38
,, 12 ,, ..	2·60	2·50	0·37	0·29

These results confirm what has been already stated as a result of the examination of potatoes treated with collodion. It is difficult to consider the increase in total sugars, or even the increase in reducing sugars, as an essential part of the rotting process. It accompanies it certainly in certain cases, but the rotting seems to be capable of taking place without

materially greater increase in the sugars than occurs when the rot is very limited as in the tubers kept at the lower temperature in the present case.

3. *Gummy Matter and Dextrin.*

	Gummy Matters.	
	Potatoes at 27° to 30° C.	Potatoes at 36°C.
	Per cent.	Per cent.
Fresh potatoes ..	1·00	1·00
After 3 days ..	1·10	1·40
„ 6 „ ..	2·10	2·50
„ 9 „ ..	2·20	1·10
„ 12 „ ..	2·80	2·20

In this case we get a curious result which does not seem, for the time being, capable of explanation. It shows the rise in the amount of gummy matter when we have learnt to associate with heat rot. It shows also the fairly large rise in the preliminary stages of rotting reached at the lower temperature in twelve days. There is an inexplicable fall in the gummy matter in the later stages of the exposure at 36°C. which demands further study and investigation.

Taken generally, these experiments with potatoes in which air is excluded by covering the surface of the tubers with an impervious layer it may be said that—

(1) the increase in ammoniacal nitrogen is much slower than when the potatoes rot in the presence of air and the more completely the air is excluded, the less is the rise in this constituent.

(2) the total sugars as well as the reducing sugar tend to increase when the potatoes are exposed to high temperatures in the absence as well as in the presence of air. It is difficult however to connect this increase directly with the rotting process.

(3) the gummy matters increase during rotting in the absence of air as well as in its presence, but the increase is slower. The association of this increase with the rotting seems very clear.

V.—Chemical Changes accompanying Heat-Rot in Carbon Dioxide and Nitrogen.

Carbon Dioxide.—During the storage of potatoes in heaps, or bags, the atmosphere round the tubers gradually tends to become more and more charged with carbon dioxide, as a result of the respiration of the tubers. As these are the conditions under which heat-rot usually becomes serious, it was interesting therefore to consider the chemical changes which would be found taking place when potatoes were placed in pure carbon dioxide. The potatoes had in this case of course to be kept in sealed jars.

The actual changes in the appearance of the potatoes so stored differ little from those already described as occurring when the surface of the tubers are sealed with paraffin wax. The rotting follows similar lines and is certainly not any more rapid than in the previous case. At 27°C. to 30°C. rotting had started before the twelfth day, the portion of the flesh immediately under the skin being greyish black.

The figures obtained in the usual determinations are as follows :—

1. *Total Nitrogen and Ammoniacal Nitrogen.*

	Total Nitrogen.		*Ammoniacal Nitrogen.*	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	1·60	1·60	0·037	0·037
After 3 days ..	1·60	1·68	0·036	0·039
„ 6 „ ..	1·60	1·70	0·050	0·052
„ 9 „ ..	1·68	1·70	0·050	0·054
„ 12 „ ..	1·64	1·70	0·054	0·067

The changes indicated by the increase in ammoniacal nitrogen evidently are taking place at the lower temperature

though more slowly than at the higher. The close connection between this increase and the phenomena we are investigating is again obvious. The amount of ammoniacal nitrogen formed is again less than in air, but very similar to that produced when this latter is excluded.

2. *Forms of Sugar.*

	Total Sugar.		*Reducing Sugar.*	
	Potatoes at 27°-30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	2·10	2·10	0·20	0·20
After 3 days ..	2·40	2·90	0·20	0·22
„ 6 „ ..	2·90	3·10	0·24	0·24
„ 9 „ ..	2·90	3·00	0·24	0·24
„ 12 „ ..	3·00	3·10	0·23	0·26

The similarity at the two temperatures investigated is again very marked. The increases of sugar in either case, however, are far less than we have obtained in the air, but are comparable with those obtained in the cases where respiration was prevented, at any rate so far as the rise in the quantity of total sugars is concerned. The increase in the amount of reducing sugars is, however, less than in this case. All the results certainly support the suggestion that the changes in sugar noted are rather part of the ordinary respiration of the potatoes at the temperatures involved, than connected with the specific question of rotting.

3. *Gummy Matters and Dextrin.*

	Gummy Matters.	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.
	Per cent.	Per cent.
Fresh potatoes ..	1·00	1·00
After 3 days ..	1·20	1·18
„ 6 „ ..	3·00	2·50
„ 9 „ ..	2·20	2·50
„ 12 „ ..	1·60(?)	2·20

Here again, with a certain amount of variation, we see a result somewhat similar to that obtained when the surface

of the potatoes was sealed up with paraffin wax. In the absence of air, there seems to be an initial rise in the gummy matter when rotting begins, which in this case tends to fall later on. This fall, after the rotting is fully established, is peculiar to these cases when air is excluded. The general conclusion as to the connection of the increase in gummy matter with the rotting is, however, clear. Its later diminution is evidently a secondary reaction whose rationale needs further investigation.

Nitrogen.—If the atmosphere of carbon dioxide in the sealed jars be replaced by nitrogen, we get a condition of things in which the changes in the potatoes can hardly be directly influenced by the surrounding medium. When potatoes were put into sealed jars in nitrogen at the usual temperatures, the rotting changes at 36°C. showed almost the same course as in carbon dioxide and the tubers are quite soft and rotten on the twelth day. At 27° to 30°C. the changes were much slower than in carbon dioxide. After six days the tubers were quite sound, and it was only after twelve days that any very considerable amount of rot had developed.

The principal difference between this case and those recorded previously is the relatively very small chemical changes which have occurred. The following figures will show this :—

1. *Total Nitrogen and Ammoniacal Nitrogen.*

	Total Nitrogen.		*Ammoniacal Nitrogen.*	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.	Potatoes at 27° to 30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	1·80	1·80	0·050	0·050
After 3 days ..	1·80	1·80	0·060	0·060
,, 6 ,, ..	1·70	1·80	0·062	0·061
,, 9 ,, ..	1·73	1·82	0·059	0·060
,, 12 ,, ..	1·80	1·80	0·067	0·080

The increase in the ammoniacal nitrogen in twelve days is 34 per cent. at 27° to 30°C. and 60 per cent. at 36°C. This increase, though small relatively to what occurs in air, is comparable with that obtained when tubers are sealed with collodion, and greater than when they are closed with paraffin wax.

2. *Forms of Sugar.*

	Total Sugars.		*Reducing Sugars.*	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.	Potatoes at 27°-30°C.	Potatoes at 36°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh potatoes ..	2·2	2·2	0·25	0·25
After 3 days ..	2·3	2·4	0·25	0·26
,, 6 ,, ..	2·1	2·2	0·25	0·26
,, 9 ,, ..	2·2	2·3	0·27	0·26
,, 12 ,, ..	2·1	2·4	0·26	0·25

Here the changes are very small, and confirms what has been said before with regard to the non-connection of the increase of sugar with the rotting process. As no respiration can take place, no increase of sugar of any kind is noticed, in spite of the fact that active rotting of the tubers is in progress.

3. *Gummy Matter and Dextrin.*

	Gummy Matter.	
	Potatoes at 27° to 30°C.	Potatoes at 36°C.
	Per cent.	Per cent.
Fresh potatoes ..	0·90	0·90
After 3 days ..	1·30	1·35
,, 6 ,, ..	1·40	0·98
,, 9 ,, ..	1·50	1·10
,, 12 ,, ..	2·80	1·80

The changes in this matter are very irregular, and it is difficult to understand their course particularly at the higher temperature. But the final result both at the

higher and at the lower temperature is that the proportion of gummy matters has doubled during the course of the exposure.

The consideration of these results of exposure of potatoes to a rotting temperature in an atmosphere of carbon dioxide or nitrogen does not lead to any modification of the conclusions reached at the end of the previous section. In these cases, just as those in which the potatoes were kept isolated from all respiratory interchange by being sealed with collodion or with paraffin wax, the increase in ammoniacal nitrogen was very much less than during rotting in air. It was still however substantial, amounting in twelve days to from 60 to 90 per cent. of the original quantity at the higher temperature. The increase of the sugars is very much less than in air, especially when the potatoes are exposed in nitrogen. The conclusion seems confirmed therefore that the large increases noted when the tubers are exposed in air are rather the result of the ordinary respiration of the potato at the high temperature of the rotting process than connected specifically with the rotting process itself. As regards the gummy matter, its increase during the rotting process, and as a result of that process, seems very clear.

VI.—The Respiration of Potatoes at the Rotting Temperature.

One more question remained. Is the rotting described closely and clearly connected with any marked increase in the production of carbon dioxide by the potato tuber? Even at low temperatures, carbon dioxide is being continually produced when potatoes are stored, but the respiration, of which this production is the evidence, is very slow. It becomes more rapid at higher temperatures and experiments were undertaken to see how far this respiration was affected by the rotting which occurs under the influence of high temperature.

The method adopted was to put the potatoes in sealed glass jars in air, as in previous experiments. Then the jar with the contained potatoes was exposed to the temperatures of 36°C. and 27° to 30°C. respectively for varying periods of time. Then the air in the jars was drawn out with an aspirator and replaced by fresh air free from carbon dioxide and the whole allowed to stand for one day in the laboratory. The air was then again extracted and the carbon dioxide in it determined by absorption in caustic potash in the usual way. In this manner the carbon dioxide formed in 24 hours after exposure to the temperatures above named for two, four, six, eight, ten and twelve days respectively was determined.

The rotting in this case took place to an extent almost exactly similar to that which occurred in the experiment previously described when the potatoes were dipped in paraffin wax.

The results obtained were as follows, the amounts of carbon dioxide produced being calculated per 100 grammes of fresh potatoes :—

Length of exposure.	(1) After exposure at 27° to 30°C.	(2) After exposure at 36°C.
	Grammes.	Grammes.
Fresh potatoes ..	0·050	0·050
After 2 days ..	0·053	0·081
,, 4 ,, ..	0·088	0·071
,, 6 ,, ..	0·094	0·072
,, 8 ,, ..	0·081	0·055
,, 10 ,, ..	0·078	0·038
,, 12 ,, ..	0·074	0·035

These results are of great interest. In both cases the exposure of the potatoes to a high temperature caused an immediate increase in the respiratory activity of the tuber. At the higher temperature, however, when rotting supervened

very quickly, there was a very rapid reduction in the amount of carbon dioxide formed when the potatoes were again placed at ordinary temperature. After exposure for twelve days the respiration had fallen to a much lower figure than before being placed at the higher temperature.

When exposed at the temperature of 27° to 30°C. the potatoes were little affected for two days ; after this the activity rapidly increased, but as the rotting became more marked the quantity of carbon dioxide produced in the time noted fell. The amount of rotting was only limited even to the end of the exposure, and the respiratory activity was still much greater than before exposure to the temperature in question.

It is evident that as soon as rotting supervenes, the amount of carbon dioxide becomes less, which is an evidence of the decrease of the respiratory activity of the potato. When the rotting is general, and the eyes are killed, the amount of carbon dioxide produced is very small indeed.

VII.—General Conclusions.

The course of heat-rot of potatoes, produced when the tubers are stored at a high temperature (above 30°C.), especially in the absence of thorough aeration, is associated with (1) a considerable increase in the ammonical nitrogen in the tuber and (2) an increase in the amount of gummy matter and dextrin contained in the potato juice. The process in connection with these two constituents takes place whether the rotting occurs in air, or when the potatoes are kept in an atmosphere of carbon dioxide or nitrogen, or when all respiratory exchange is prevented by dipping the tubers in collodion or in paraffin wax. In air, in addition, there is a considerable increase in the amount of sugars, but this increase is much lower when respiration is prevented, and it is probable that it is not connected with the rotting process.

The rotting is not accompanied by any material increase in acidity or alkalinity of the juice of the tubers, but when

the rotting is marked the amount of the enzyme catalase is very much reduced, until the process is complete and the potato completely soft or rotten. The rotting produced by heat seems to result in a considerable decrease in the respiration of the tuber, as measured by the amount of carbon dioxide produced by potatoes which have been exposed to the temperatures involved.

The primary purpose of these experiments, namely to find a method of detecting, by chemical means, the first onset of heat rotting in potatoes, has not been achieved, but the results obtained appear to be of considerable interest nevertheless, and to indicate clearly something of the character of the changes involved in the process studied.

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